Copernicus Global Land Operations
"Vegetation and Energy"
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PRODUCT USER MANUAL

SURFACE ALBEDO
COLLECTION 1KM
VERSION 1

Issue I1.40

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List of Acronyms

ALDH	Directional-Hemispheric Albedo (“Black-sky albedo”)
ALBH	Bi-Hemispheric Albedo (“White-sky albedo”)
ATBD	Algorithm Theoretical Basis Document
BELMANIP	BEnchmark Land Multisite ANalysis and Intercomparison of Products
BRDF	Bidirectional Reflectance Distribution Function
CEOS	Committee on Earth Observation Satellite
CEOS-LPV	CEOS Land Product Validation Subgroup
CYCLOPES	Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites
CGLS	Copernicus Global Land Services
CV	Coefficient of Variability
ECV	Essential Climate Variables
EFDC	European Fluxes Database Cluster
FLUXNET	Flux Network
GCOS	Global Climate Observing System
GIO	GMES Initial Operation (now Copernicus)
GL	Global Land
GTOS	Global Terrestrial Observing System
HDF	Hierarchical Data Format
JRC	Global Terrestrial Observing System
LSA SAF	Land Surface Analysis Satellite Application Facility
MI	Moran's Index
MISR	Multi-angle Imaging Spectro-radiometer
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NMOD	Number of valid observations used for the normalisation
NRT	Near Real Time
POLDER	Polarization and directionality of Earth Reflectances
PROBA-V	VEGETATION sensor on PRoject for On Board Autonomy platform
PUM	Product User Manual

QAR	Quality Assessment Report
QA4ECV	Quality Assurance for Essential Climate Variable
QFLAG	Quality Flag
REF_NOR	Normalized Reflectance
RMSD	Root Mean Square Deviation
SA	Surface Albedo
SALVAL	Surface ALbedo VALidation tool
SEVIRI	Spinning Enhanced Visible and InfraRed Imager (EUMETSAT)
SPOT	Satellite Pour l'Observation de la Terre
SURFRAD	SURFace RADiation Network
SWIR	Short Wave Infrared
TOA	Top Of Atmosphere
TOC	Top Of Canopy
VGT	VEGETATION sensor onboard SPOT satellites
VNIR	Visible and Near Infrared
WGS	World Geodetic System
WMO	World Meteorological Organization
ZIP	Compressed archive file format

EXECUTIVE SUMMARY

The Copernicus Global Land Service (CGLS) is earmarked as a component of the Land 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.

From 1st January 2013, the Copernicus Global Land Service is providing Essential Climate Variables like the Leaf Area Index (LAI), the Fraction of Absorbed Photosynthetically Active Radiation absorbed by the vegetation (FAPAR), the surface albedo, the Land Surface Temperature, the soil moisture, the burnt areas, the areas of water bodies, and additional vegetation indices, are generated every hour, every day or every 10 days on a reliable and automatic basis from Earth Observation satellite data.

This Product User Manual (PUM) describes the CGLS Surface Albedo (SA) Version 1 products, derived from SPOT/VEGETATION Collection 2 and PROBA-V Collection 1 daily data. The SA product is a 30-days composite, updated every 10 days using a moving window. The product is projected on a regular latitude/longitude grid with a resolution of 1/112° (approx. 1km at the equator). It is delivered over the whole globe (from -180°E to +180°W and from +75°N to -60°S). It is provided in NetCDF4 format containing the broadband directional and hemispheric albedo values, its associated error, and a quality flag.

1 BACKGROUND OF THE DOCUMENT

1.1 SCOPE AND OBJECTIVES

The PUM is the primary document that users have to read before handling the products.

It gives an overview of the product characteristics, in terms of algorithm, technical characteristics, and main validation results.

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 explains the differences with the previous version of the product.
- Chapter 5 summarizes the validation procedure and the results.
- Chapter 6 gives indications about the product usage.

Users' requirements are recalled in Annex.

1.3 RELATED DOCUMENTS

1.3.1 Applicable documents

AD1: Annex I – Technical Specifications JRC/IPR/2015/H.5/0026/OC to Contract Notice 2015/S 151-277962 of 7th August 2015

AD2: Appendix 1 – Copernicus Global land Component Product and Service Detailed Technical requirements to Technical Annex to Contract Notice 2015/S 151-277962 of 7th August 2015

AD3: GIO Copernicus Global Land – Technical User Group – Service Specification and Product Requirements Proposal – SPB-GIO-3017-TUG-SS-004 – Issue I1.0 – 26 May 2015.

1.3.2 Input

Document ID	Descriptor
CGLOPS1_SSD	Service Specifications Document of the Copernicus Global Land Service.
CGLOPS1_SVP	Service Validation Plan of the Copernicus Global Land service.

CGLOPS1_ATBD_TOCR1km-V1.5	Algorithm Theoretical Basis Document of the normalized Top of Canopy Reflectance (TOC-r) Collection 1km Version 1.5
CGLOPS1_ATBD_SA1km-V1	Algorithm Theoretical Basis Document of the Surface Albedo Collection 1km Version 1 products.
CGLOPS1_PUM_TOCR1km-V1.5	Product User Manual of the normalized Top of Canopy Reflectance (TOC-r) Collection 1km Version 1.5
GIOGL1_VR_SA1km-V1	Validation report of the SPOT/VGT surface albedo Collection 1km Version 1.4 products.
CGLOPS1_VR_SA1km-PROBAV-V1.5	Validation report of the PROBA-V surface albedo Collection 1km Version 1.5 products

1.3.3 External document

SPOT-VGT	http://www.spot-vegetation.com/index.html
SPOT-VGT User Guide	User guide of the SPOT/VEGETATION data, available on http://www.vgt.vito.be/userguide/book_1/2/26/263/s10sm.html
PUM_PROBA-V-C1	Product User Manual PROBA-V Collection 1 (see http://www.vito-eodata.be/PDF/image/PROBAV-Products_User_Manual.pdf)

2 ALGORITHM

The algorithm has been defined by Météo-France/CNRM in the framework of the FP5/CYCLOPES project, and applied operationally to the SPOT-1&2/VEGETATION-1&2 data in the framework of the FP7/geoland2 project. Beside the NRT production, the whole SPOT/VGT archive has been processed to get a consistent time series of more than 15 years. The algorithm follows the approach separating atmospheric correction, directional normalisation by inversion of a BRDF (Bidirectional Reflectance Distribution Function) model, and albedo determination (Figure 1).

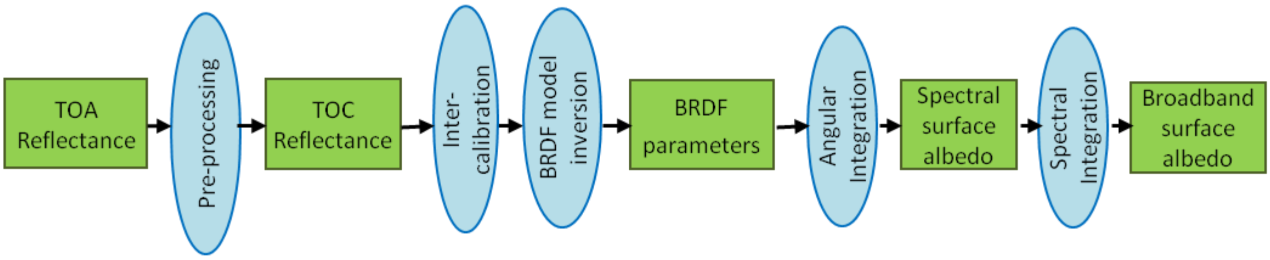

Figure 1: flow chart of the surface albedo algorithm

2.1 OVERVIEW

The surface albedo quantifies the fraction of the irradiance reflected by the surface of the Earth. It provides information on the radiative balance, thus on the temperature and water balance. It can be measured taking into account the general physical concept described below.

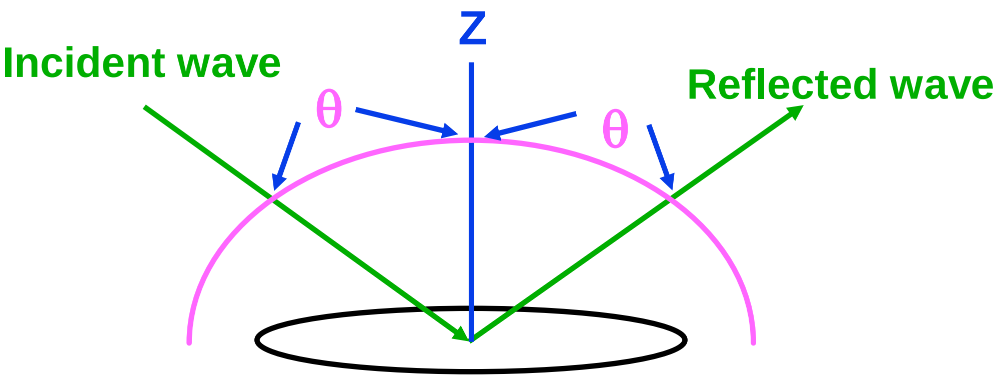

Figure 2: General physical concept of the albedo

The directional albedo (a^{dh}) or directional-hemispherical reflectance (also called black-sky albedo) is defined as the integration of the bi-directional reflectance over the viewing hemisphere. It assumes all energy is coming from a direct radiation from the sun. It is computed for the local solar noon.

$$a^{dh}(\lambda\lambda\theta_s, \varphi_s) = \frac{1}{\pi}\int_0^{2\pi}\int_0^{\pi/2} \rho_\lambda(\theta_s, \theta_v, \varphi).\cos\theta_v.\sin\theta_v.d\theta_v.d\varphi \qquad \text{Eq. 1}$$

The hemispherical albedo (a^{bh}) or bi-hemispherical reflectance (also called white-sky albedo) is defined as the integration of the directional albedo over the illumination hemisphere. It assumes a complete diffuse illumination. It is computed as:

$$a^{bh}(\lambda) = \frac{1}{\pi}\int_0^{2\pi}\int_0^{\pi/2} a^{dh}(\lambda, \theta_s, \varphi_s)\cos\theta_s \sin\theta_s d\theta_s d\varphi_s \qquad \text{Eq. 2}$$

The spectrally-integrated albedos are called broadband albedos as:

$$a = \frac{\int_{300nm}^{4000nm} E(\lambda(\lambda).a(\lambda d\lambda}{\int_{300nm}^{4000nm} E(\lambda(\lambda).}$$

Three broadband albedos are defined:

- Over the visible (PAR) range [0,4µm – 0,7µm]
- Over the near-infrared range [0,7µm – 4µm]
- Over the total shortwave band [0,3µm – 4µm] (equation above)

2.2 INPUT DATA

The input data of the Surface Albedo Version 1 processing line are the BRDF coefficients derived from:

- the SPOT/VGT Collection 2 Top of Atmosphere (TOA) reflectance products provided by the SPOT/VEGETATION program (http://free.vgt.vito.be/).
- the from the PROBA-V Collection 1 Top Of Atmosphere (TOA) L2A reflectance products provided by the PROBA-V ground segment (http://proba-v.vgt.vito.be/).

Since April 1998 and till May 2014, the VEGETATION sensor has been operational on board the SPOT 4 and 5 earth observation satellite system, providing a global observation of the world on a daily basis. The instrumental concept relies on a linear array of 1728 CCD detectors with a large field of view (101°) in four optical spectral bands described in Table 1 and Figure 3. At the radiometric level, the two VEGETATION instruments are very similar, but yet there are some differences. Firstly, the spectral bands of the VGT1 and VGT2 sensors have been defined as similar as possible, but the spectral response functions are not identical (Figure 3) (Fensholt et al., 2009) causing small differences in radiometric response. The VGT website reports changes up to 1.6% for Blue, 5.4% for Red, 2.5% for NIR, 4.6% for SWIR and 12.1% for NDVI for vegetated surfaces (http://www.vgt.vito.be/faqnew). Secondly, there is a difference in calibration accuracy due to the improved calibration methods used for VGT2. The effect is small for most spectral bands, but can result in a reflectance bias of 6.3% for NIR and 3.4% for NDVI (http://www.vgt.vito.be/faqnew).

The spatial resolution is 1.15 km at nadir and presents minimum variations for off-nadir observations. The 2200 km swath width implies a maximum off nadir observation angle of 50.5°. About 90% of the equatorial areas are imaged each day, the remaining 10% being imaged the next day. For latitudes higher than 35° (North and South), all regions are acquired at least once a day. The multi-temporal registration is about 300 meters.

Table 1: Spectral characteristics of VEGETATION 2 sensor

Acronym	Centre (nm)	Width (nm)	Potential Applications
B0	450	40	Continental ecosystems -Atmosphere
B2	645	70	Continental ecosystems
B3	835	110	Continental ecosystems
SWIR	1665	170	Continental ecosystems

The PROBA-V satellite was launched on 6th May 2013 and was designed to bridge the gap in space-borne vegetation measurements between SPOT-VGT (March 1998 – May 2014) and the Sentinel-3 satellites, the first one launched in 2016, which will ensure the continuity of the service. The mission objective is to ensure continuity with the heritage of the SPOT-VGT mission.

The optical design of PROBA-V consists of three cameras. Each camera has two focal planes, one for the short wave infrared (SWIR) and one for the visible and near-infrared (VNIR) bands. The VNIR detector consists of four lines of 5200 pixels. Three spectral bands were implemented, comparable with SPOT-VGT: BLUE, RED, and NIR (see Table 2). The SWIR detector is a linear array composed of three staggered detectors of 1024 pixels. The spectral response functions of the four spectral bands from the three PROBA-V cameras are compared to those of SPOT/VEGETATION-1 and -2 in Figure 3.

PROBA-V operates at an altitude of 820 km in a sun-synchronous orbit with a local overpass time at launch of 10:45 h. Because the satellite has no onboard propellant, the overpass time is expected to gradually differ from the at-launch value. The instrument has a Field Of View of 102°, resulting in a swath width of 2295 km. This swath width ensures a daily near-global coverage (90%) and full global coverage is achieved every 2 days.

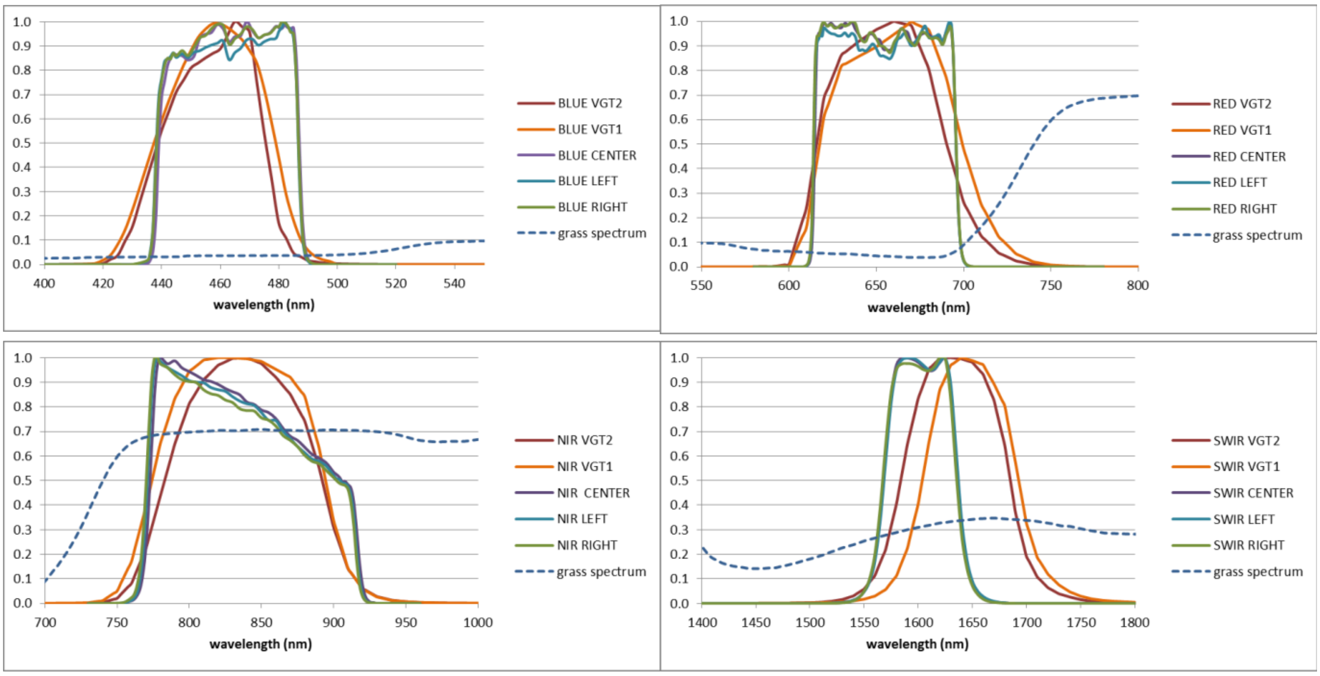

Figure 3: Spectral Response Functions of VGT1, VGT2, and the three PROBA-V cameras, superimposed with a spectrum of green grass (Blue, Red, NIR and SWIR bands, respectively).

Table 2: Spectral characteristics of the PROBA-V sensor

Acronym	Centre (nm)	Width (nm)	Potential Applications
B0	463	46	Continental ecosystems–Atmosphere
B2	655	79	Continental ecosystems
B3	845	144	Continental ecosystems
SWIR	1600	73	Continental ecosystems

The instrument plane layout is shown in Figure 4. Observations are taken at resolutions between 100 m and 180 m at nadir up to 350 m and 660 m at the swath extremes for the VNIR and SWIR channels, respectively (Francois et al. 2014). Finally, PROBA-V products are disseminated at 333 m and 1 km resolution.

L2A segments are projected L1C segment data captured by either one of the different cameras (left, center or right). More information can be found in PUM_PROBA-V-C1]. Each camera can be individually switched on/off, and hence not every orbit provides three segments. In total, around 90 segments per day can be retrieved. Each camera is composed of 2 sensors, the VNIR sensor and the SWIR sensor, with a slightly different off-nadir along track viewing direction. The target on ground is imaged at different time and with different viewing angles. This specific technical concept makes the angular configurations of observations in VNIR and SWIR bands are different, and hence different angular information is provided.

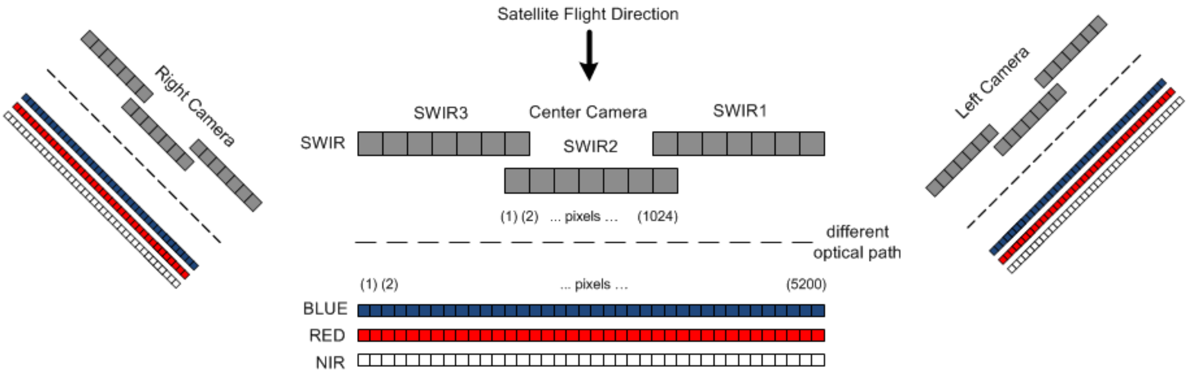

Figure 4: PROBA-V instrument layout

More information on the PROBA-V processing can be found in Sterckx et al. (2014) and Dierckx et al. (2014). Information on the PROBA-V Collection 1 is available on http://proba-v.vgt.vito.be/en/quality/product-evaluation/collection_1_change_summary.

2.3 ALBEDO COMPUTATION

The retrieval of the BRDF coefficients is described in the ATBD of the TOC-r product [CGLOPS1_ATBD_TOCR1km-V1.5]. In particular, the semi-empirical kernel-driven reflectance model by Roujean et al. (1992) is inverted over the observations of the compositing period to correct the bidirectional effects. The model describes the bidirectional reflectance distribution function (BRDF) as a linear combination of three terms, themselves weighted by three parameters:

$$\rho(\theta_s,\theta_v,\phi) = k_0 + k_1 f_1(\theta_s,\theta_v,\phi) + k_2 f_2(\theta_s,\theta_v,\phi) \qquad \text{Eq. 3}$$

θ_s, θ_v, ϕ are respectively the solar zenith, view zenith and relative azimuth angles, while f_1 and f_2 are the geometric and volume scattering functions respectively, and k_i are the weighting parameters of the f_i functions.

Inserting the reflectance model (Eq.3) in the equationsEq.1 and Eq.2 gives the expressions

$$a_\lambda^{dh}(\theta_{s\_n}) = k0.I_0^{dh}(\theta_{s\_n}) + k1.I_1^{dh}(\theta_{s\_n}) + k2.I_2^{dh}(\theta_{s\_n}) \qquad \text{(Eq.4)}$$

and

$$a_{\lambda}^{bh} = k0.I_0^{bh} + k1.I_1^{bh} + k2.I_2^{bh} \quad \text{(Eq.5)}$$

where

$$I_i^{dh}(\theta_{s\_n}) = \frac{1}{\pi}.\int_0^{2\pi}\int_0^{\frac{\pi}{2}} f_i(\theta_s,\theta_v,\varphi).\cos(\theta_v).\sin(\theta_v).d\theta_v.d\varphi \quad \text{(Eq.6)}$$

and

$$I_i^{bh} = 2.\int_0^{\pi/2} I_i^{dh}\cos(\theta_s)\sin(\theta_s)d\theta_s \quad \text{(Eq.7)}$$

are the respective angular integral of kernel fixed functions which are pre-computed and stored in look up tables.

The broadband albedo is defined as the integral of spectral albedo over a certain wavelength range, weighted by the spectral irradiance. Since the integral can be approximated as a weighted sum of the integrand at discrete values of the integration variable, broadband albedo may be expressed as a linear combination of the spectral albedo values in the available spectral channels.

The broadband albedos are derived from the spectral quantities by applying linear transformations:

$$a_{\gamma}^{xh} = c_{0\gamma}^{xh} + \sum_j c_{j\gamma}^{xh}.a_j^{xh} \quad \text{(“x” = “d” or “b”)} \quad \text{(Eq.8)}$$

In order to better take into account the differences in the spectral properties of various land cover types, regression coefficients ($c_{0\gamma}^{xh}$ and $c_{j\gamma}^{xh}$) are set-up, depending on the presence of snow.

More details are provided in the ATBD [CGLOPS1_ATBD_SA1km-V1].

2.4 ERROR ESTIMATE

Thanks to the linear relationship between the BRDF model parameters and the spectral albedo quantities, standard (“1-sigma”) error estimates for the latter can conveniently be retrieved from the error covariance matrix $\mathbf{C}_k$ of the model parameters (Lutch and Lewis, 2000).

$$\sigma[a_j] = \sqrt{\mathbf{I}^T \mathbf{C}_k \mathbf{I}} \quad \text{(Eq.9)}$$

Assuming that the errors of the spectral albedo values are uncorrelated, the error estimate for broadband albedo quantities is given by

$$\sigma\left[a_{\gamma}^{xh}\right]=\sqrt{\sigma^{2}\left[regression\right]+\sum_{j}\left(c_{j\gamma}^{xh}\right)^{2}\sigma^{2}\left[a_{j}^{xh}\right]} \qquad \text{(“}x\text{”=”}d\text{” or “}b\text{”)} \qquad \text{(Eq.10)}$$

where σ^2 [*regression*] denotes the residual variance of the linear regression.

These (theoretical) error estimates for the generated albedo parameters represent the most general quality indicator delivered by the algorithm. Since all transformations applied to derive albedo are linear, the validity of the Gaussian assumption for the error structure of the input data propagates to the retrieved albedo estimates. The validity of the theoretical error estimates is strictly speaking restricted to the framework of the applied BRDF-model.

3 PRODUCT DESCRIPTION

The **Surface Albedo Collection 1km V1** product follows the following naming standard:

c_gls_<Acronym>_<YYYYMMDDHHMM>_<AREA>_<SENSOR>_V<VERSION>

where

- <Acronym> is the short name of each product and variable: ALDH for directional (or black-sky) Albedo (Eq.4) or ALBH for hemispherical (or white-sky) Albedo (Eq.5)
- <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. Note that HHMM is always 0000.
- <AREA> gives the spatial coverage of the file. The SA Collection 1km products are by default only available as global coverage (GLOBE). User specific regions can be obtained through a custom order.
- <SENSOR> gives the name of the sensor used to retrieve the product, so VGT or PROBAV
- <VERSION> shows the processing line version used to generate these Albedo Collection 1km products. The version denoted as M.m.r (e.g. 1.0.1), with 'M' representing the major version (e.g. V1), 'm' the minor version (starting from 0) and 'r' the production run number (starting from 1) (Table 3).

Table 3: Explanation in version numbering and recommendations for using efficiently the products

Versions	Differences	Recommendations
Major	Significant change to the algorithm.	Do not mix various major versions in the same applications, unless it is otherwise stated.
Minor	Minor changes in the algorithm	Can be mixed in the same applications, but require attention or modest modifications
Run	Fixes to bugs and minor issues. Later run automatically replaces former	Consider it as a drop-in replacement

3.1 FILE FORMAT

The ALDH and ALBH products are distributed as internally compressed, multi-band Network Common Data Form version 4 (netCDF4) with metadata attributes compliant with version 1.6 of the Climate & Forecast conventions (CF V1.6). The ALDH contains the following full-resolution bands (layers or netCDF variables):

- AL_DH_VI: Broadband directional albedo over visible spectrum [0.4, 0.7µm]
- AL_DH_VI_ERR: Error on AL_DH_VI
- AL_DH_NI: Broadband directional albedo over near-infrared spectrum [0.7-4µm]
- AL_DH_NI_ERR: Error on AL_DH_NI
- AL_DH_BB: Broadband directional albedo over full spectrum [0.3-4µm]
- AL_DH_BB_ERR: Error on AL_DH_BB
- AL_DH_QFLAG: the bitwise quality flag of the product
- NMOD: the number of valid observations during the synthesis period
- LMK: land cover mask based upon the GLC-2000 classes

Similarly structure, the ALBH contains the following full-resolution bands (layers or netCDF variables):

- AL_BH_VI: Broadband hemispherical albedo over visible spectrum [0.4, 0.7µm]
- AL_BH_VI_ERR: Error on AL_DH_VI
- AL_BH_NI: Broadband hemispherical albedo over near-infrared spectrum [0.7-4µm]
- AL_BH_NI_ERR: Error on AL_DH_NI
- AL_BH_BB: Broadband hemispherical albedo over full spectrum [0.3-4µm]
- AL_BH_BB_ERR: Error on AL_DH_BB
- AL_BH_QFLAG: the bitwise quality flag of the product
- NMOD: the number of valid observations during the synthesis period
- LMK: land cover mask based upon the GLC-2000 classes

In addition to the netCDF data files, the following files are provided:

- a xml file containing the metadata conform to INSPIRE2.1.
- A quicklook in a coloured geo-tiff format. The quicklook sub-sampled to 25% in both horizontal and vertical direction from the AL_DH_BB or AL_BH_BB layer.

For a more user-friendly view of the XML contents in a browser, an XSL transformation file can downloaded at 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.

Each netCDF4 file corresponds to a global region.

3.2 PRODUCT CONTENT

3.2.1 Data File

The physical ranges of ALDH and ALBH, and of their respective errors, are given in Table 4 and in Table 7. The physical values are retrieved by:

$$PhyVal = DN * Scale\_Factor + Add\_Offset$$

where the scaling factor and the offset are given in the Table 5.

Table 4: Range of values and scaling factors of ALDH, ALBH and their errors.

	AL_DH_VI, AL_DH_NI, AL_DH_BB, AL_BH_VI, AL_BH_NI, AL_BH_BB	AL_DH_VI_ERR, AL_DH_NI_ERR, AL_DH_BB_ERR, AL_BH_VI_ERR, AL_BH_NI_ERR, AL_BH_BB_ERR
Minimum value	0	0
Maximum value	1	1
Maximum DN value	10000	10000
Invalid flag	65535	65535
Out of range by value superior to the maximum physical value	65533	65533
Out of Range by value inferior to the minimum physical value	65534	65534
Scale_factor	0.0001	0.0001
Add_Offset	0	0

The parameter NMOD corresponds to the number of measurements used to calculate the albedo, and hence reflects the number of valid observations during the synthesis period. The physical values are equal to the digital number within the range [0, 60].

The parameter LMK is a land cover map based upon the GLC2000 classes. It integrates the class “salt lakes” at global scale. The digital numbers are equal to the sum of 200 and of the class number of the GCL2000 map.

The quality flag (QFLAG) is coded on 2 bytes and must be read bit per bit (Table 5), except for the missing value equal to 65535.

Table 5: Description of the quality flag of AL-DH and AL-BH products. “XX” on bits 7, 8 and 9 means “DH” or “BH” depending on the product.

* indicates propagated from TOC-r Quality flag	Bit = 0	Bit = 1
Bit 1*: Land/Sea	Land	Sea
Bit 2*: Snow status	Clear	Snow
Bit 3*: Cloud/Shadow status	Clear	Suspect
Bit 4*: Aerosol status	Pure	Mixed
Bit 5*: Aerosol source	MODIS	Latitudinal gradient
Bit 6*: Input Status	OK	Out of range or invalid
Bit 7: AL-XX-VI status	OK	Out of range or invalid
Bit 8: AL-XX-NI status	OK	Out of range or invalid
Bit 9: AL-XX-BB status	OK	Out of range or invalid
Bit 10*: Red band (B2) saturation status	OK	Saturated
Bit 11*: Blue band (B0) saturation status	OK	Saturated

The netCDF files contain a number of metadata attributes:

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

Table 6: Description of netCDF file attributes

Attribute name	Description	Data Type	Example for AL-BH derived from SPOT/VEGETATION
Conventions	Version of the CF-Conventions used	String	CF-1.6
title	A description of the contents of the file	String	10-daily Broadband Hemispherical Surface Albedo 1KM: GLOBE 2013-12-03T00:00:00Z
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	2017-09-19 Processing line GEO1 Albedo 1km
references	Published or web based references that describe the data or methods used to produce it.	String	https://land.copernicus.eu/global/products/sa
archive_facility	Specifies the name of the institution that archives the product	String	VITO
product_version	Version of the product (VM.m.r)	String	V1.4.1
time_coverage_start	Start date and time of the temporal coverage of the input data.	String	2013-11-15T00:00:00Z
time_coverage_end	End date and time of the temporal coverage of the input data	String	2013-12-15T23:59:59Z
platform	Name(s) of the orbiting platform(s)	String	SPOT_5
sensor	Name(s) of the sensor(s) used	String	VEGETATION_2
identifier	Unique identifier for the product	String	urn:cgls:global:albh_v1_1km:ALBH_201312030000_GLOBE_VGT_V1.4.1
parent_identifier	Identifier of the product collection for the product in Copernicus Global Land Service metadata catalogue	String	urn:cgls:global:albh_v1_1km
long_name	Extended product name	String	Broadband Hemispherical Surface Albedo
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, Offline or Reprocessing)	String	Reprocessing
copyright	Text to be used by users when referring to the data source of this product in publications (copyright notice)	String	Copernicus Service information 2017

Table 7: Description of netCDF attributes for variable AL_BH_BB

Attribute	Description	Data Type	Examples for AL_BH_BB layer
CLASS	Dataset type		
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'sudunits).	String	surface_albedo
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	Broadband hemispherical albedo over total spectrum
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	0.0001
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'sudunits library. Empty or omitted for dimensionless variables. Fractions should be indicated by scale_factor.	String	1
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, 10000
_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	65535
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	65535
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	65533,65534
flag_meanings	Descriptive words or phrases for each flag value.	Same as data variable	Out_of_range_superior_to_physical_maxOut_of_range_inferior_to_physical_min

Table 8: Description of netCDF attributes for coordinate dimensions (latitudes and longitudes)

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'sudunits).	String	longitude
long_name	A descriptive name that indicates a variable's content. This name is not standardized. Used when a standard name is not available (FDOB layers).	String	longitude
units	Units of a the variable's content, taken from Unidata'sudunits library.	String	degrees_east
axis	Identifies latitude, longitude, vertical, or time axes.	String	X
_CoordinateAxisType	Label used in GDAL library	String	Lon

Table 9: 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 a the variable's content, taken from Unidata'sudunits 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'sudunits library.	String	standard

Table 10: Description of netCDF attributes for the grid mapping variable

Attribute	Description	Data Type	Example
GeoTransform	Six coefficients for the affine transformation from pixel/line space to coordinate space, as defined in GDAL'sGeoTransform	String	-180.0000000000 0.0089285714 0.0 80.0000000000 0.0 -0.0089285714
_CoordinateAxisTypes	Label used in GDAL library	String, blank separated	GeoXGeoY
_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"]]

3.2.2 Quicklook

The quicklook is a geo-referenced TIFF (GeoTIFF) file and derived from the broadband variables: AL_DH_BB or AL_BH_BB. The spatial resolution is sub-sampled to 25% in both directions, hence a quicklook is 1/16th of the size of the data layer.

The quicklook is coded in 1 byte and provided with an embedded color table. The data layer is scaled from 2 bytes to a single byte using offset=0 and scale=0.025 in the valid data range (0-10000). As such the values over 65530 are set to 255.

The embedded color table uses the following legend (Table 11)

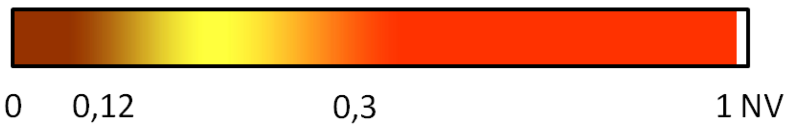

Table 11: Color coding for quicklook images

3.3 PRODUCT CHARACTERISTICS

3.3.1 Projection and Grid Information

The product is displayed in a regular latitude/longitude grid (plate carrée) with the ellipsoid WGS 1984 (Terrestrial radius=6378km). The resolution of the grid is 1/112° (approx. 1km at the equator).

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.)

3.3.2 Spatial information

The Surface Albedo product is provided from longitude 180°E to 180°W and latitude 75°N to 60°S. Any areas that are not covered (e.g. northern latitudes in wintertime) are filled with no-data values.

3.3.3 Temporal Information

The Surface Albedo products are 30-days composites, updated every 10 days using a moving window.Each product is characterized by four dates (Table 12).

Table 12: Overview of temporal characteristics of the products

	In filename	In netCDF attributes	In ISO metadata
Nominal or actual date	yes	:identifier, :title, time coordinate variable	fileIdentifier, citation :date, citation :title
Start date	no	:time_coverage_start	EX_temporalExtent: beginPosition
Stop date	no	:time_coverage_end	EX_temporalExtent: endPosition
Production date	no	:history	citation:editionDate

The temporal information "YYYYMMDDHHmm" in the filename is thus the actual or "**nominal**" date corresponding to the product value

For example, the file c_gls_ALDH_200408130000_GLOBE_VGT_V1.4.1.nc corresponds to the synthesis period from 26/07/2004 to 25/08/2004. The day 13/08/2004 is the day where the sum of weights of the weighting function is the same on each side of this date.

<u>Important note</u>: The "nominal" date is the date to take in consideration for any analysis.

The temporal coverage or extent information, as provided in

- The ISO metadata (xml file) through "EX_TemporalExtent : beginPosition" and "EX_TemporalExtent : endPosition" in "YYYY-MM-DDTHH:MM::SS format
- The time_coverage_start and time_coverage_end global attributes in the netCDF file

defines the beginning and the end of the 30-day time period, respectively. The end date of each 30-day time period is set to the 05th, 15th or 25th day of the month. The same months and days re-occur per year (Table 13), with only variations in Feb-March due to the leap year.

Table 13: Pattern for start, nominal and end dates in MM-DD format

Start date	Nominal date	Stop date
12-06	12-24	01-05
12-16	01-03	01-15
12-26	01-13	01-25
01-06	01-24	02-05
01-16	02-03	02-15
01-26	02-13	02-25
02-03	02-21	03-05
02-04	02-22	03-05
02-13	03-03	03-15
02-14	03-03	03-15
02-23	03-13	03-25
02-24	03-13	03-25
03-06	03-24	04-05
03-16	04-03	04-15
03-26	04-13	04-25
04-05	04-23	05-05
04-15	05-03	05-15
04-25	05-13	05-25
05-06	05-24	06-05
05-16	06-03	06-15
05-26	06-13	06-25
06-05	06-23	07-05
06-15	07-03	07-15
06-25	07-13	07-25
07-06	07-24	08-05
07-16	08-03	08-15
07-26	08-13	08-25
08-06	08-24	09-05
08-16	09-03	09-15
08-26	09-13	09-25
09-05	09-23	10-05
09-15	10-03	10-15
09-25	10-13	10-25
10-06	10-24	11-05
10-16	11-03	11-15
10-26	11-13	11-25
11-05	11-23	12-05
11-15	12-03	12-15
11-25	12-13	12-25

3.4 DATA POLICIES

EU law[1] grants free access to Copernicus Sentinel Data and Service Information for the purpose of the following use in so far as it 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.

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Where the user communicates to the public on or distributes the **original** surface albedo 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 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 product was generated by the land service of Copernicus, the Earth Observation and monitoring programme of the European Union. The research leading to the current version of the product has received funding from various European Commission Research and Technical Development programmes. The product is based on SPOT/VGT 1km data (© CNES) or on PROBA-V 1km data (© ESA and distributed by VITO).*"

The user accepts to inform the production and distribution centre of their publications through the science & technical support contact below.

[1] European Commission, Regulation (EU) No 377/2014 and Commission Delegated Regulation (EU) No 1159/2013.

3.5 ACCESS AND CONTACTS

The Surface Albedo product is available through the Copernicus Global Land service website at the address: http://land.copernicus.eu/global/products/sa

Accountable Contact: European Commission, Directorate-General Joint Research Centre, Italy
Email address: copernicuslandproducts@jrc.ec.europa.eu

Scientific & Technical support contact e-mail address:
http://land.copernicus.eu/global/contactpage.

4 DIFFERENCES BETWEEN VERSIONS

The differences in algorithms between the Surface Albedo V1 products are summarized in Table 14.

V1.4 and earlier versions are derived from the SPOT/VEGETATION Collection 2 dataset. This collection contains some artefacts, amongst others a sun-earth distance error [Toté, 2017], which affects this version of the Surface Albedo [GIOGL1_VR_SA1km-V1]. The cloud and snow detection mechanisms of the TOA to TOC processing come from the original CYCLOPES algorithm. Indeed, the snow detection was implemented based on spectral variations of snow (Dozier, 1989) as a set of thresholds on TOA reflectances and the Normalized Difference Snow Index (NDSI). The cloud detection was implemented based on the same screening method developed by Hagolle et al. (2004), with thresholds associated to each of the bands empirically tuned and validated at global scale in April 1999.

V1.5 and later versions are derived from the PROBA-V Collection 1 dataset. The cloud and snow detection use the information contained in the status map of the PROBA-V input data to identify cloudy and snowy pixels.

All other characteristics (coding values, projection, grid, etc...) remain the same.

Table 14 : Algorithm differences between successive versions of Surface Albedo product

SA versions	Algorithm differences
Version 1.4 or earlier	SPOT/VGT C2 input data, Own snow & cloud detection. Inter-calibration to POLDER sensor.
Version 1.5 or later	PROBA-V C1 input data (2014-NRT), Snow & cloud detection based on Status Map of input data. Inter-calibration to SPOT/VGT2.

5 VALIDATION RESULTS

5.1 OVERVIEW

The SPOT/VGT Surface Albedo V1.4 products have been validated [GIOGL1_VR_SA1km-V1] in the framework of FP7/geoland2 project.

The PROBA-V Surface Albedo V1.5 products have been validated [CGLOPS1_VR_SA1km-PROBAV-V1.5], focusing in the overlap period between SPOT/VGT and PROBA-V (November 2013 to May 2014).

The validation reports [GIOGL1_VR_SA1km-V1 and CGLOPS1_VR_SA1km-PROBAV-V1.5] are available on the Global Land service website (http://land.copernicus.eu/global/products/SA).

5.2 VALIDATION PROCEDURE

The validation procedure is described in the CGLS Service Validation Plan [CGLOPS1_SVP]. The protocols and metrics were defined to be consistent with the Land Product Validation (LPV) group of the Committee on Earth Observation Satellite (CEOS) for the validation of satellite-derived land product. Several criteria of performance were considered in agreement with previous global validation exercises (Camacho et al., 2013; Garrigues et al., 2008; Weiss et al., 2007), the OLIVE (On Line Validation Exercise) tool hosted by CEOS CAL/VAL portal (Weiss et al., 2014), and with the recent CEOS LPV Global LAI product validation good practices. Recent results of PROBA-V were performed using Surface Albedo VALidation (SALVAL) tool, developed by EOLAB (Sánchez-Zapero et al. 2017), providing transparency and traceability in the validation procedure. SALVAL was designed to be compliant with the CEOS-LPV sub-group and QA4EO recommendations, and results from SALVAL allow evaluating the fitness-for-purpose according to the user requirements.

5.3 VALIDATION RESULTS

5.3.1 SPOT/VGT SA V1.4 products

Several criteria of performance were assessed: completeness, spatial consistency, temporal consistency, precision (inter-annual and intra-annual) and the overall assessment of the spatio-temporal consistency with similar products. First, an inter-comparison with existing global products (e.g. MODIS C5) was performed at 6-km spatial resolution and 10-days frequency to analyse the spatial and temporal consistency of the SPOT/VGT products during the 2006-2007 period. The BELMANIP-2 global network of sites was used to perform the statistical analysis. The accuracy was quantified by direct comparison with FLUXNET ground measurements over a few number of homogeneous sites. Moreover, a special focus over Europe, including Land-SAF MSG Albedo product, was carried out. Main results and conclusions are summarized below:

Product Completeness

- For high latitudes and equatorial regions, the lack of spatial continuity is very high, especially during winter in the north hemisphere (and even larger when QFLAG information is considered).
- This is one of the main drawbacks of the SPOT/VGT SA and the other polar orbiting satellite products, in contrast to products derived from geostationary sensors such as the Land-SAF MSG albedo products with no gaps.

Spatial Consistency

- SPOT/VGT and MODIS products presented very similar global spatial distributions of broadband albedo quantities, withlarge areas (America, Africa, Asia and Oceania) displaying mean differences within ±0.01. SPOT/VGT albedo displays slightly higher values mainly over Europe, North Africa, South-East Asia, whereas MODIS albedo is higher over Boreal and Polar areas (bias up to 0.1) where the impact of snow/ice is more important.
- The focus over Europe showed larger differences over northern latitudes, mainly when comparing with MSG albedo.

Temporal consistency

- Temporal variations of SPOT/VGT SA product are very consistent with both ground observations and other satellite products. The product responds generally well to strong albedo changes due to persistent snow events and to smooth seasonal variations over the different vegetation biomes.
- However, as compared to other products, SPOT/VGT SA fails to reproduce sporadic (i.e., few dates) snow events, and tends to exhibit larger fraction of missing values over snow.
- The main discrepancy was found over desert sites: the seasonal variation of the SPOT/VGT directional albedo was found higher than other products, which is a consequence of the error in the calculation of the sun-Earth distance affecting the Collection 2 of SPOT/VGT data.

Inter-Annual Precision

- The temporal profiles are very smooth and highly precise over calibration sites with an inter-annual RMSD of 0.008 units.

Inter-Annual Precision

- SPOT/VGT, MODIS C5 presented very similar distributions of the smoothness. Most of the delta values are below 0.01 which demonstrates the high stability at short time scale of the SA products.

Overall Spatio-Temporal Consistency

- The SPOT/VGT albedo performs remarkably well with MODIS, with a mean bias and RMSD for the shortwave black-sky albedo lower than 0.006 and 0.03 (13%) respectively.

For the visible and NIR directional albedo products the overall performance is about 0.04 (30%) and 0.02 (8%), respectively, with no bias.

- The performance metrics are better if only snow-free pixels are considered. This overall performance figures are however land-cover dependent and large uncertainties are found over some biomes (or regions) or specific periods (e.g. wintertime).
- As refers to the period, the uncertainties are lower from April to October and increases notably from November to March, which may be partly explained by the effect of snow cover, large BRDF errors due to larger illumination angles or higher cloudiness over the northern hemisphere during the winter months.
- Land Cover types:
    - SPOT/VGT and MODIS shortwave albedo quantities are very consistent for all biomes, with mean bias within ±0.01. SPOT/VGT shortwave albedo is slightly higher than MODIS except for Snow/Ice. Best performance (better than 10%) was found for Broadleaf forest and Bare Areas, and similar performances of about 15% for the other types. For Snow/Ice the RMSD is 0.06 (20%).
    - The comparison with MSG over Europe shows larger uncertainties for NLF (0.04, 40%) and better performances for bare areas (0.02, 5%) and herbaceous types (0.03, 10%).

Accuracy Assessment

- The limited comparison with field data for FLUXNET homogeneous sites where diffuse fraction was measured showed a RMSD of about 0.05 (target accuracy) and albedo underestimation for mixed snow/vegetation pixels.
- The performance (RMSD) for snow-free values was 0.03 with a slight positive bias of SPOT/VGT albedo of only 0.005.

Concluding remarks

The validation report demonstrated that the SPOT/VGT SA products are comparable to that of MODIS MCD43B3 C5 albedo products, except for Snow/Ice pixels. Assuming that the MODIS albedo product is a good validated reference, we conclude that SPOT/VGT Albedo product is of good quality over the globe, presenting some limitation under snow conditions. Temporal profiles are consistent with satellite and ground variations and generally reproduce well variations due to strong snow cover changes, but however fails to detect sporadic snow falling events. The anomaly detected in the VEGETATION processing chain related the standardization of the solar illumination angles is responsible of the larger seasonality of albedo observed over calibration sites. This anomaly, however, does not introduce apparent effects over vegetated sites, where seasonal variations in the vegetation canopy dominate the observed changes in albedo along the year. As compared with MODIS very small biases was observed for all biomes (except for snow) with an overall performance for the shortwave albedo quantities (DH, BH) of about 0.03 (13%) for all BELMANIP-2 pixel, and of about 0.02 (10%) for snow-free pixels.

SPOT/VGT albedo V1.4 products reached good performance for most of the criteria examined (Table 15). However, the error field seems not realistic and the Quality Flag may discard reliable snow retrievals.

Table 15: Summary of Product Evaluation. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

Criteria	Performance	Comments
Product Completeness	-	Main limitations over Northern latitudes in wintertime and Equatorial areas
Spatial Consistency	+	Very good consistency with MODIS products (MCD43B best retrievals)
Temporal Consistency	+	Some limitation observed to detect spurious snowfall events
Inter-Annual Precision	+	Typically better than 0.01
Intra-Annual Precision	+	RMSD of 0.008 over desertic *'calibration'* sites
Spatio-Temporal Consistency	+	RMSD between 0.01 and 0.03 depending on land cover type (except for Snow/Ice ~ 0.06) as compared with MODIS
Accuracy	+	RMSD better than 0.05 over snow-free data; Limited ground dataset; Larger discrepancies expected over Snow/Ice targets
Error bar	-	Larger than expected in many situations; Low variability around the world
Quality Flag (Bit 6- Input status)	-	Pixels flagged as 'invalid input' provides reliable estimations over snow targets

5.3.2 PROBA-V SA V1.5 products

The quality assessment of PROBA-V was mainly focused on the consistency of PROBA-V and SPOT/VGT SA products for the overlap period (November 2013 –May 2014). Moreover, MODIS C5 products were considered for the statistical inter-comparison during whole 2014, as well as to investigate the consistency of the temporal trajectories. The following main criteria were assessed: completeness, spatial consistency, temporal consistency, inter-annual precision and the overall assessment of the spatio-temporal consistency with similar products. The accuracy was quantified by direct comparison with ground measurements coming from 17 SURFRAD and EFDC stations over homogeneous sites at 1-km^2. Main results and conclusions are summarized below:

Product Completeness

- The spatio-temporal continuity of PROBA-V SA V1.5 products is poor (up to 100% of missing data) over northern regions (winter time) and equatorial areas (all dates), in line to that observed for SPOT/VGT products.
- The highest percentage (42% in average) of global missing observations was found during winter period in northern hemisphere, and the lowest during July and August (~15%).
- In general, higher fraction (differences between 5% and 20%) of missing data was found in PROBA-V compared to SPOT/VGT SA V1.5 products.
- Per biome type, the larger fraction of missing values was found for EBF, showing PROBA-V larger fraction of gaps than SPOT/VGT. For the rest of biomes, similar trend was found between PROBA-V and SPOT/VGT.
- Per continental region, PROBA-V provides lower fraction of missing data than SPOT/VGT over most of the regions except in SOAM (PROBA-V provides more gaps than SPOT/VGT) and NOAM (PROBA-V provides more gaps than SPOT/VGT during November 2013 to February 2014).
- The temporal length of missing values was very consistent between PROBA-V and SPOT/VGT SA V1.5 products. MODIS C5 products show the shorter length of gaps.

Spatial Consistency

- Global maps and maps over sub-continental regions of PROBA-V SA V1.5 products showed reliable distributions for both black-sky and white-sky albedos in all spectral domains, without finding spatial artifacts. Ancillary layers (errors, NMOD and QFLAG) showed reliable and consistent values. However, a sharp latitudinal transition over northern hemisphere (around ~50º) was observed during December 2013, January 2014, February 2014 and December 2014 due to some limitation on cloud screening of PROBA-V input data.
- In terms of bias, global maps of differences between PROBA-V and SPOT/VGT SA V1.5 products showed systematic positive bias (PROBA-V > SPOT/VGT) for NIR and shortwave around the whole globe except for snow (random sign). For visible domain, no systematic bias was found, with the exception of desertic areas (positive bias).
- Global distributions of residuals showed typically around 36% of AL-DH-VI residuals showing optimal consistency (60% considering the target uncertainty level). For AL-DH-NI and AL-DH-BB ~50% of pixels showed optimal consistency (~70-75% target). Slightly lower percentage of optimal cases was found for white-sky albedos.
- Poor consistency pixels are randomly distributed around the globe, with the exception of arid and semi-arid regions, where optimal spatial consistency was found.
- PROBA-V showed positive spatial autocorrelation over the six LANDVAL homogeneous sites located over EBF, DBF, NLF, Herbaceous, Shrubs and desertic areas of interest. However, PROBA-V tends to provide generally lower spatial correlation (MI) than SPOT/VGT and MODIS C5, and higher CV.

Temporal Consistency

- For EBF, PROBA-V SA V1.5 provides similar temporal trajectories than both references (SPOT/VGT and MODIS C5), displaying low temporal variability in ~50% of cases. For the rest of cases, some temporal noise was observed in all satellite products.
- For the rest of biome types and conditions, PROBA-V temporal variations reproduce well rapid changes of SA values (large in magnitude) due to seasonal changes in phenology or snow events (except in 10% of LANDVAL herbaceous cases), as well as smooth SA transitions, consistent to that found in both satellite references (SPOT/VGT and MODIS C5). Two main additional observations were found:
    - For LANDVAL sites, in around 15% of DBF, 12% of herbaceous, 20% of shrublands, and 12% of bare areas, PROBA-V displays some temporal variability as compared to both references (flat temporal trajectories) in NIR domain (also affecting to the total spectrum).This effect was mainly observed during the period from November 2013 to January 2014 over southern hemisphere (i.e. summer season).
    - For NLF, in around 10% of cases a temporal shift corresponding to one dekad was observed between PROBA-V and SPOT/VGT during the dates showing transitions between snow and snow-free seasons.
- The cross-correlation between PROBA-V and SPOT/VGT temporal variations was higher than 0.7 typically in more than 50% (visible and total spectrum) and in more than 40% (NIR) of the sites for the different biomes in all spectral channels, with the exception of EBF and snow where poor correlations were found. Lower cross-correlations were found in the comparison with MODIS C5.
- Changes in albedo due to snow events or phenology captured in ground data are well reproduced in PROBA-V. However, lower number of valid retrievals was found in PROBA-V compared with MODIS C5 and SPOT/VGT during snow seasons.

Intra-Annual Precision (smoothness)

- PROBA-V SA V1.5 products show a good intra-annual precision, almost identical to that of SPOT/VGT SA V1.5 and MODIS C5 products in visible domain and total shortwave, achieving high stability at short time scale.
- In NIR domain, slight δ values of PROBA-V albedo products were found as compared to both references. This result could be indicative of slight degraded precision at short time scale.

Overall Spatio-Temporal Consistency

- PROBA-V versus SPOT/VGT:
    - Scatter-plots and uncertainty statistics between PROBA-V and SPOT/VGT SA V1.5 (best quality pixels) products over LANDVAL sites during the overlap period show good consistency for all spectral bands, with correlations higher than 0.93 for all spectral domains. Slight positive bias of ~5% was found for NIR and shortwave, and almost no mean bias for visible.

   - 39%, 43% and 42% (67%, 73%, and 75%) of pixels showed optimal (target) level of consistency between PROBA-V and SPOT/VGT for AL-DH-VI, AL-DH-NI and AL-DH-BB, with worse results (~3-5%) for white sky albedos.
   - Per value range, median bias close to zero was found for all albedo range in visible domain. For NIR and shortwave, PROBA-V tends to provide higher albedo values than SPOT/VGT for all ranges except for snow (highest ranges).
   - For visible domain, low bias (<3%, with random sign) was found for all biome type with larger negative bias for snow (-7.3%). Percentage of pixels within the optimal (GCOS) level ranges from 17% (worse case, snow class) to 88% (best case, bare areas).
   - For NIR and shortwave, systematic positive bias (<10% for NIR, and <8% for shortwave) was found for all classes except for snow, where the main discrepancies were found. Percentage of pixels within the optimal (GCOS) level ranges from 18% in NIR and 21% in shortwave (worse case, snow class) to 69% and 63% (best case, bare areas).
- PROBA-V versus MODIS C5:
   - The comparison between PROBA-V V1.5 and MODIS C5 SA for the whole 2014 year showed higher correlations(R>0.91) regardless the spectral domain. Positive biases of ~5%, ~10% and ~15% were found for visible, NIR and total spectrum.
   - The percentages of pixels between the optimal/target levels were 22%/46%, 21%/44%, and 7%/24% for AL-DH-VI, AL-DH-NI and AL-DH-BB, showing similar values for AL-BH retrievals.
   - Per range value, for visible domain PROBA-V provides higher values than MODIS for SA<0.4, and the opposite trend was found for SA>0.4. For NIR, median positive bias was found for SA<0.5, and median positive bias ~0 for SA>0.5. For the total spectrum, large positive bias was found, positive for SA<0.5 and negative for SA>0.5.
   - Per biome type, no systematic trend of sign of the bias was found for visible domain, with typically between 15% and 30% of pixels achieving the optimal for all biome type. For NIR, positive bias (typically <15%) was found for all classes except for snow (-0.6%). The percentage of pixels showing optimal consistency in NIR domain was less than 30% for all classes, with significant better results in bare areas (49%). Similar results were found for shortwave than for NIR, but showing large discrepancies (large bias and less than 16% of pixels achieving optimal consistency for all classes).

<u>Accuracy Assessment</u>

- The comparison of PROBA-V SA V1.5 with field data for 17 SURFRAD and EFDC homogeneous sites shows RMSD of 0.042 for the 2014 year, showing improved results in MODIS C5 (0.029). PROBA-V provides systematic overestimation (mean bias of 0.032, 22.1%), whereas MODIS C5 provides low bias (0.006, 4.9%).
- Very low percentage of PROBA-V pixels within the GCOS requirements was found (4% of 274 samples). In case of MODIS C5, 18.1% of pixels achieved the GCOS requirements.

Concluding remarks

The Quality Assessment of the PROBA-V SA V1.5 products reached, in overall, enough level of quality to be delivered to users for most of the criteria evaluated, reaching the validated stage 1 at the CEOS LPV hierarchy. However, some limitations were observed:

- No systematic differences were found between PROBA-V and SPOT/VGT SA V1.5 for visible domain. However, systematic positive bias of ~5% was found for NIR and shortwave. Larger differences, with random bias, were found for snow pixels. The comparison with MODIS C5 showed larger bias (~5%, ~10% and ~15% for visible, NIR and shortwave), partly explained by the different broadband ranges.
- Large positive bias of PROBA-V (0.032, 22.1%) was found compared to 17 stations (N=274 samples) during the 2014. It is recommend to expand the analysis to confirm this tendency.
- PROBA-V provides large number of missing data than SPOT/VGT (5% - 20%), mainly observed over snow pixels. PROBA-V provides lower number of valid retrievals over snow targets than SPOT/VGT and MODIS C5.

The main results of each quality criteria of this study are summarized in Table 16.

Table 16: Summary of PROBA-V SA V1.5 product evaluation. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

QA Criteria	Performance	Comments
Product Completeness	**-**	Main limitations over Northern latitudes in wintertime and Equatorial areas. Similar results than SPOT/VGT products, showing larger percentage of missing data.
Spatial Consistency	**±**	Reliable and consistent values over the whole globe, without observing spatial artifacts with the exception of a sharp latitudinal transition ~50º during winter season. Global distributions showed systematic positive bias (PROBA-V > SPOT/VGT) for NIR and BB, and bias 0 for VI. Global distributions of residuals showed ~36% of cases within the optimal level for VI, and 50% for NI and BB. Good repeatability over well-known homogenous areas. Positive spatial autocorrelation (MI) and low spatial variability (CV). MI lower than both references (SPOT/VGT and MODIS C5), and higher CV.
Temporal Consistency	**+**	Reliable temporal variations for most of the cases compared with satellite reference products and ground observations. Cross-correlation between PROBA-V and SPOT/VGT greater than 0.7 in more than 50% (VI and BB) and 40% (NI) of cases except in EBF and snow. Worse results compared to MODIS C5.
Intra-Annual Precision	**+**	Similar smoothness than both references (SPOT/VGT and MODIS C5), showing slightly higher δ values in NI.
Overall Spatio-Temporal Consistency	**±**	PROBA-V vs SPOT/VGT shows high correlation (R>0.93) and low scattering, with almost no mean bias in VI and systematic positive mean bias of ~5% in NI and BB (except in snow). 39%, 43% and 42% (67%, 73%, and 75%) of pixels showed optimal (target level) for VI, NI and BB. Comparison of PROBA-V and SPOT/VGT per biome type showed low bias (<3%, random sign) for VI, and positive bias for NI and BB in all biome types. The exception was the snow class, with negative bias. Good performance as compared with MODIS C5 in terms of correlations (R>0.91), with relative mean bias of ~5%, ~10% and ~15% for VI, NI and BB, during the whole 2014 year. Percentage of pixels between the optimal (target) levels: 22% (46%), 21% (44%), and 7% (24%) for VI, NI and BB. Comparison of PROBA-V and MODIS C5 per biome type showed no systematic trend of the sign of bias for VI, and positive bias for NI and BB for all classes except for snow (negative).
Accuracy Assessment	**-**	PROBA-V: N=274; B=0.032 (22.1%); RMSD=0.042; Snow free conditions. 4% of pixels within GCOS. Improved results for MODIS C5 using the same sampling: B=0.006 (4.9%); RMSD= 0.029; 18.1% of pixels within GCOS.

5.4 OUTCOME OF THE QUALITY MONITORING ON SPOT/VGT SA V1.4 PRODUCTS

The Quality Monitoring is performed on the Global Land products. The objective is to verify that the recent operational products keep the same level of quality during the period under study than the products of the fully validated reference period. The procedure, criteria and metrics are the same than those applied for the validation exercise above.

Three quality monitoring exercises were performed on SPOT/VGT Albedo V1.4 products between 1st January 2013 and mid-2014 since the production stopped in May 2014, at the end of the SPOT/VEGETATION mission.

The outcomes of the quality monitoring analysis performed on 2013 and 2014 SPOT/VGT Surface Albedo products are included into the Validation Report [GIOGL1_VR_SA1km-V1]. Compared to the analysis summarized above (§ 5.3.1), the accuracy assessment by comparison of satellite-derived products with ground measurements was improved using in-situ data from several networks (SURFRAD, ARM BSRN and AMERIFLUX). The evaluation demonstrates that the recent SPOT/VGT Albedo products keep the same level of quality that the validated products (2006 and 2007) for all the criteria examined (Table 17).

Table 17: Summary of evaluation of 2013-2014 SPOT/VGT Albedo product. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

QM Criteria	Performance	Comments
Product Completeness	-	Main limitations over Northern latitudes in wintertime and Equatorial areas. Highly affected the Needle-leaf forest biome in wintertime (northern hemisphere). Pixel flagged as 'invalid input' provides reliable estimations over snow.
Spatial Consistency	+	Optimal. Good consistency against the reference validated period. Very consistent spatial distributions of retrievals per biome and region.
Temporal Consistency	±	Very reliable seasonal and inter-annual variations but large variations observed over desertic sites (due to incorrect calculation of sun/Earth distance in the SPOT/VGT data)
Intra-annual Precision	+	The temporal profiles are very smooth (intra-annual precision better ~0.005)
Inter-annual Precision	+	RMSD better than 0.01 (2%), and Bias < 1% over desert 'calibration' sites Distributions are very consistent and no bias with validated reference products. High stability in term of Bias, better than 1%.
Spatio-Temporal Consistency Analysis	+	Distributions very consistent with reference validated products for all biome types. RMSD ~20% and Bias <1% between recent and validated.
Accuracy	+	RMSD of 0.03 (~18%) for snow-free season (May-September) over SURFRAD stations. Same accuracy metrics obtained for MODIS products.
Regional Assessment	±	Good consistency with MODIS products. Better agreement was found for Bare Areas and Croplands (RMSD~10%). Larger discrepancies over boreal areas.

Since the final objective of the quality assessment analysis is to verify how much the products are compliant with the users' requirements (see Annex: Review of Users Requirements), we set-up a compliance matrix (Table 18). The last column states in how far these requirements are met by SPOT/VGT surface albedo products.

Table 18: Compliance matrix of GCOS and WMO requirements for SPOT/VGT Surface albedo products.

Requirement	Source	Objective	Match
Horizontal Resolution	GCOS	200/500m	No (1km)
	WMO High resolution NWP	Goal (0.5km) Breakthrough (4km) Threshold (10km)	Breakthrough (1km<4km)
	WMO Nowcasting/VSRF	Goal (1km) Breakthrough (5km) Threshold (10km)	Goal
Temporal Resolution	GCOS	Daily	No, SPOT/VGT Temporal Resolution = 10 days
Observing Cycle	WMO High resolution NWP	Goal (1h) Breakthrough (3h) Threshold (12h)	No, SPOT/VGT observing cycle: 30 days
	WMO Nowcasting/VSRF	Goal (1d) Breakthrough (3d) Threshold (90d)	Threshold, SPOT/VGT observing cycle: 30 days
Timeliness	WMO High resolution NWP	Goal (1h) Breakthrough (3h) Threshold (12h)	No
	WMO Nowcasting/VSRF	Goal (0.5d) Breakthrough (1d) Threshold (3d)	Threshold
Accuracy	GCOS	Max(5%; 0.0025)	No, RMSD=20% snow-free pixels
	WMO High resolution NWP	Goal (5%) Breakthrough (10%) Threshold (20%)	Threshold over snow-free pixels (RMSD=20%)
	WMO Nowcasting/VSRF		
Stability	GCOS	Max(1%; 0.001)	Yes, in terms of Bias <1% over desert calibration sites. In terms of RMSD is 2%

6 LIMITATIONS AND RECOMMENDATIONS

The Surface Albedo product is computed with a composition period of 30 days. This large length is to guarantee a minimum of cloudless scenes at global scale to perform the inversion and, then, to avoid gaps into the products. However, this yields obviously some limitations in regard to the capability of the SA product to capture the evolution of some targets with a sufficient degree of accuracy, especially during the period when the state of the surface changes rapidly.

Cloud pixels at the border of the orbit segment can result in an underestimate of cloud shadow (in case projected outside the segment), or cloud dilate (in case radius of spheric morphologic filter falls outside the segment) in the TOC-r pre-processing [CGLOPS1_ATBD_TOCR1km-V1.5]. In such case, shadow pixels are used as 'clear' and, hence, can introduce some noise in the BRDF model inversion.

Any misclassification of cloud and snow pixels in the input data can introduce some noise in the albedo products unless the additional rules in the TOC-r pre-processing [CGLOPS1_ATBD_TOCR1km-V1.5] overrule this classification. For instance, overestimating clouds reduce the number of valid observations for the BRDF model inversion. In the worst case, the inversion is not possible and the albedo value is missing; in better case, the BRDF model is less constraint during the inversion and the resulting uncertainty is higher on the retrieved albedo value. Another impact is that clouds wrongly identified as "snow" are not discarded and can create unrealistic high albedo values.

The atmospheric correction, currently based upon a monthly climatology derived from MODIS AOT [CGLOPS1_ATBD_SA1km-V1], will be improved in further evolution of the albedo product using the SMAC scheme (Rahman et Dedieu, 1994) with ancillary datasets provided by the Copernicus Atmosphere Monitoring Service.

Note that the use of bit 6 and bits 10-11 of Quality flag (Table 5) removes most of the valid SA retrievals over snow targets in PROBA-V products. Then, it is not recommended to use this flag information for snow applications.

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ANNEX: REVIEW OF USERS REQUIREMENTS

According to the applicable document [AD2] and [AD3], the user's requirements relevant for the surface albedo product are:

- **Definition**:
  - Refers to the hemispherically integrated reflectance of the Earth's surface in the range 0.4 – 0.7µm (or other specific short-wave) (CEOS)
  - Albedo is further defined spectrally (broadband) or for spectral bands of finite width, and according to its bi-directional reflectance properties (black-sky or white-sky albedo) (CEOS)

- **Geometric properties**:
  - Pixel size of output data shall be defined on a per-product basis so as to facilitate the multi-parameter analysis and exploitation.
  - The baseline datasets pixel size shall be provided, depending on the final product, at resolutions of 100m and/or 300m and/or 1km.
  - The target baseline location accuracy shall be 1/3rd of the at-nadir instantaneous field of view
  - pixel co-coordinates shall be given for centre of pixel

- **Geographical coverage**:
  - Geographic projection: regular lat-long
  - Geodetical datum: WGS84
  - Coordinate position: centre of pixel
  - Window coordinates:
    - Upper Left:180°W-74°N
    - Bottom Right: 180°E 56°S

- **Ancillary information:**
  - the number of measurements per pixel used to generate the synthesis product
  - the per-pixel date of the individual measurements or the start-end dates of the period actually covered
  - quality indicators, with explicit per-pixel identification of the cause of anomalous parameter result

- **Accuracy requirements**:
  - Baseline: wherever applicable the bio-geophysical parameters should meet the internationally agreed accuracy standards laid down in document "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 UNFCC (GCOS-154, 2011)" (Table 19)

- **Target**: considering data usage by that part of the user community focused on operational monitoring at (sub-) national scale, accuracy standards may apply not on averages at global scale, but at a finer geographic resolution and in any event at least at biome level.

Table 19: GCOS Requirements for surface albedo as Essential Climate Variables [GCOS-154, 2011].

Variable/ Parameter	Horizontal Resolution	Temporal Resolution	Accuracy	Stability
Black and White-sky albedo (GCOS#154, 2011)	1 km	Daily to weekly	Max(5%; 0.0025)	Max(1%; 0.0001)
Black and White-sky albedo (GCOS#200, 2016)	200/500m	Daily	Max(5%; 0.0025)	Max(1%; 0.001)

In a recent update of the GCOS requirements [GCOS#200, 2016], there is a distinction between the products targeted for "adaptation" and "modeling" that results in different needs for the horizontal resolution. In CGLS, we focus on modeling requirements as they are the main users targeted (Table 19). Note, as well, that the figure for stability requirements in absolute term has been corrected (0.001 instead of 0.0001)

Other requirements come from the "WMO Rolling Requirement Review" that aids the setting of the priorities to be agreed by WMO Members and their space agencies for enhancing the space based Global Observing System. In this context, GCOS has provided input for the systematic climate observation elements of the "WMO Observing Requirements Database" (https://www.wmo-sat.info/oscar/variables/view/54). The GCOS requirements are only partly consistent with this process in that they provide only target but not "breakthrough" or "threshold" (i.e. minimum) requirements. GCOS also provides requirements on stability that are not currently included in the WMO requirements database.

The "WMO Observing Requirements Database" specifies requirements on the surface albedo for climatologic applications at three quality levels (Table 20):

- Threshold (T): Minimum requirement;
- Breakthrough (B): Significant improvement;
- Goal (G): Optimum, no further improvement required

Table 20: WMO Requirements for Earth surface albedo [source: https://www.wmo-sat.info/oscar/variables/view/54].

Application	Uncertainty (%)			Horizontal resolution (km)			Observing cycle (h:hours, d:days)			Timeliness (h:hours, d:days)		
	G	B	T	G	B	T	G	B	T	G	B	T
High resolution NWP	5	10	20	0.5	4	10	1h	3h	12h	1h	3h	12h
Nowcasting/VSRF	5	10	20	1	5	10	1d	3d	10d	0.5d	1d	3d
Climate-TOPC (deprecated)	5	7	10	1	2	10	1d	3d	30d	30d	45d	90d

The WMO Observing Requirements Database specifies uncertainties in absolute parameter units. The stated “goal” uncertainty requirement of 5% is thus equivalent to the GCOS requirement (Table 19).