Copernicus Global Land Operations
"Vegetation and Energy"
" CGLOPS-1"
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SCIENTIFIC QUALITY EVALUATION

PROBA-V SURFACE ALBEDO

COLLECTION 1KM

VERSION 1

Issue I1.00

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List of Acronyms

AD	Applicable document
ALBEDOVAL	Surface Albedo Validation
AL-BH	White-sky albedo (Bi-Hemispherical ALbedo)
AL-DH	Black-sky albedo (Directional ALbedo)
ATBD	Algorithm Theoretical Basis Document
AsiaFlux	Regional research FLUXNET network in Asia
BA	Bare Areas
BB	Broad Band
BELMANIP	BEnchmark Land Multisite ANalysis and Intercomparison of Products
BRDF	Bidirectional Reflectance Distribution Function
C	Cultivated
CEOS	Committee on Earth Observation Satellite
CGLOPS1	Copernicus Global Land OPerationS Lot 1
CGLS	Copernicus Global Land Service
CNES	Centre National d'Etudes Spatiales
C5	Collection 6
C6	Collection 6
DAAC	Distributed Active Archive Center
DBF	Deciduous Broadleaf Forest
EBF	Evergreen Broadleaf Forest
EC	European Commission
EFDC	European Fluxes Database Cluster
EFFIS	European Forest Fire Information System
EOLAB	Earth Observation LABoratory
ERR	ERRor (Uncertainty ancillary layer)
EU	European Union
FLUXNET	FLUXes NETwork (network of regional networks)
FP7	Seventh Framework Programme
GCOS	Global Climate Observing System
GLC	Global Land Cover
H	Herbaceous
ImagineS	Implementation of Multi-scale Agricultural Indicators Exploiting Sentinels
JRC	Joint Research Centre
LANDVAL	LAND VALidation network
LPV	Land Product Validation Subgroup
MAR	Major Axis Regression
MODIS	Moderate Resolution Imaging Spectroradiometer
MCD	MODIS products from Terra+Aqua
N	Number of samples
NARMA	Natural Resource Monitoring in Africa
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NEON	National Ecological Observatory Network
NI	Near Infra-Red
NIR	Near-infrared
NLF	Needle-Leaf Forest
NMOD	NuMber of valid Observations During the synthesis period
NWP	Numerical Weather Prediction

OLIVE	On Line Validation Exercise
OLS	Ordinary Least Squares
ORNL	Oak Ridge National Laboratory
OzFlux	TERN (Terrestrial Ecosystem Research Network) network of observation sites across Australia and New Zealand
PDF	Probability Density Function
PUM	Product User Manual
PROBA-V	Project for On-Board Autonomy satellite, the V standing for vegetation
QAR	Quality Assessment Report
QA4ECV	Quality Assurance for Essential Climate Variable
QFLAG	Quality Flag
RMSD	Root Mean Square Deviation
S	Shrublands
SA	Surface Albedo
SAVS	Surface Albedo Validation Sites
SQE	Scientific Quality Evaluation
SPOT /VGT	Satellite Pour l'Observation de la Terre / VEGETATION
SSD	Service Specifications Document
SURFRAD	SURFace RADiation Network
SVP	Service Validation Plan
TOA	Top Of Atmosphere
TOC	Top Of Canopy reflectance
TOC-r	Top Of Canopy reflectance
UNFCCC	United Nations Framework Convention on Climate Change
V1	Version 1
VI	Visible domain
VR	Validation Report
VSRF	Very Short Range Forecasting
WGCV	Working Group on Calibration and Validation (CEOS)
WGS	World Geodetic System
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

The Scientific Quality Evaluation of recent PROBA-V SA Collection 1km Version 1 (2017 year) is carried out in order to check if the recent operational products keep the same level of quality than validated products (2014). The methodology follows, as much as possible, the guidelines, protocols and metrics defined by the Land Product Validation (LPV) group of the Committee on Earth Observation Satellite (CEOS).

The analysis focuses mainly the comparison between PROBA-V SA Collection 1km V1 2017 products with reference validated 2014 year. This study covers the period during 1st of January to 31th of December, and the equivalent period of the reference dataset was included in the analysis. Reference SPOT/VGT SA V1 products during the 2012 were also included in the study in order to assess the impact of the change of sensor input data. Several criteria of performance are evaluated at global scale and over the sub-continental West Africa region. The evaluated criteria include product completeness, spatial and temporal consistency, statistical consistency per biome type, and precision. The analysis at global scale is performed over a network of 725 validation sites (LANDVAL) representing global conditions. The temporal realism of the temporal variations was evaluated over sites showing specific fire events and sites with available ground data. The accuracy was assessed over 5 sites with ground data coming from NEON stations. MODIS MCD43A3 C6 surface albedo products were included in the evaluation of the temporal realism and in the accuracy assessment for benchmarking.

In overview, results demonstrate that the 2017 SA Collection 1km V1 products keep a similar level of quality than the validated (2014), with overall RMSD values of 0.057 for AL-DH-VI, 0.035 for AL-DH-NI and 0.042 for AL-DH-BB, and low bias of -0.5%, 1.7% and 1.4%. The comparison between PROBA-V 2017 products and SPOT/VGT SA V1 2012 products confirms the positive bias observed in the PROBA-V SA V1 validation report in NIR and total shortwave, showing positive mean differences of 10.5% for NIR and 8.7% for the total shortwave. In addition, PROBA-V Collection 1km V1 tends to provide similar temporal variations than MODIS C6 over specific fire events, and similar temporal trend than ground measurements over 5 NEON sites for snow-free conditions. Finally, the accuracy assessment over 5 NEON stations showed RMSD of 0.041 and positive bias of 0.025 (14.3%). Only 8% of PROBA-V retrievals achieved the GCOS uncertainty requirements, and 20.6% and 54% of cases achieved the optimal and target requirements coming from the technical user group of the Copernicus Global Land.

It is recommended to the PROBA-V mission to improve the cloud detection algorithm of the current Collection 1, and to reprocess the PROBA-V archive.

1 BACKGROUND OF THE DOCUMENT

1.1 SCOPE AND OBJECTIVES

This document presents the results of the annual Scientific Quality Evaluation (SQE) of the SA Collection 1km Version 1 2017 products based on PROBA-V observations, distributed in a demonstration status.

The quality evaluation is performed over global datasets coming from the Copernicus Global Land Service Portal Distribution (http://land.copernicus.vgt.vito.be/PDF/portal/Application.html) covering a period from 1st of January to 31th of December 2017 at 10-days temporal frequency.

The main objective is to verify that the recent Collection 1km products keep the same level of quality in the period under study than the validated products. For this purpose, a comparison with PROBA-V V1 product during the 2014 year is conducted. SA Collection 1km V1 products based on SPOT/VGT data during the 2012 year was also included in the comparison, for benchmarking.

1.2 CONTENT OF THE DOCUMENT

This document is structured as follows:

- Chapter 2 recalls the user requirements, and the expected performance.
- Chapter 3 describes the methodology for quality assessment, the metrics and the criteria of evaluation.
- Chapter 4 presents the results of the analysis.
- Chapter 5 summarizes the main conclusions of the study.
- Chapter 6 makes recommendations based upon the results.

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 of the Global Component of the Copernicus Land Service.
CGLOPS1_SVP	Service Validation Plan of the Global Land Service
CGLOPS1_ATBD_SA1km-V1	Algorithm Theoretical Basis Document of the SA Collection 1km Version 1
GIOGL1_ATBD_PROBA2VGT	Algorithm Theoretical Basis Document of PROBA to VGT Pre-processing.
GIOGL1_VR_SAV1	Validation report of SPOT/VGT Collection 1km Surface Albedo Version 1
CGLOPS1_VR_SA1km-PROBAV-V1.5	Validation report of PROBA-V Surface Albedo from PROBA-V Collection 1km Version 1.5

1.3.3 Output

Document ID	Descriptor
GLOPS1_PUM_SA1km-V1	Product User Manual summarizing all information about the Surface Albedo Collection 1km Version 1

1.3.4 External documents

Document ID	Descriptor
PUM_PROBA-V-C1	Product User Manual PROBA-V Collection 1 (see http://www.vito-eodata.be/PDF/image/PROBAV-Products_User_Manual.pdf)

Product User Manual of PROBA-V data, available at http://proba-v.vgt.vito.be/sites/proba-v.vgt.vito.be/files/product_user_manual.pdf

Validation report of the cloud mask applied on PROBA-V data. Available at http://proba-v.vgt.vito.be/sites/proba-v.vgt.vito.be/files/documents/probav_cloudmask_validation_v1.0.pdf

https://earthobservatory.nasa.gov/IOTD/view.php?id=89496 Fire event in Chile, 2017.

https://earthobservatory.nasa.gov/IOTD/view.php?id=89570 Fire event in Chile, 2017.

https://www.nbcnews.com/slideshow/chile-ravaged-worst-fires-its-modern-history-n712556	Fire event in Chile, 2017.
https://earthobservatory.nasa.gov/IOTD/view.php?id=89389	Fire event in Argentina, 2017.
https://earthobservatory.nasa.gov/IOTD/view.php?id=90470	Fire event in Siberia, Russia, 2017.
http://effis.jrc.ec.europa.eu/applications/fire-news/fire/9219/detail	Fire event in Pedrógão Grande, Portugal, 2017.
https://earthobservatory.nasa.gov/IOTD/view.php?id=90427	Fire event in Pedrógão Grande, Portugal, 2017.
https://earthobservatory.nasa.gov/NaturalHazards/view.php?id=91421&eocn=home&eoci=nh	Fire event in California, USA, 2017.

2 Review of Users Requirements

According to the applicable document [AD2] and [AD3], the user's requirements relevant for surface albedo products 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 1)

- **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 1: GCOS Requirements for surface albedo as Essential Climate Variable [GCOS-200, 2016].

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

In the last 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 1).

Additionally, the Technical User Group of the Copernicus Global Land Service [AD3] has recommended new optimal and target requirement levels for SA accuracy, as showed in Table 2.

Table 2: Copernicus Global Land Operations Service (CGLOPS) product requirements for Surface Albedo products.

	Optimal	Target
Accuracy Surface Albedo	10%	- 0.03 (absolute) for SA<0.15 - 20% for SA>0.15

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 (see Table 3):

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

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 1).

Table 3: WMO Requirements for surface albedo [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

3 REVIEW OF THE PROBA-V COLLECTION 1KM V1 PRODUCTS QUALITY

The scientific validation of the PROBA-V SA Collection 1km Version 1 products is described in the Quality Assessment Report [CGLOPS1_VR_SA1km-PROBAV-V1.5], which shows the quality evaluation during the first year of PROBA-V data (December 2013- December 2014). The study focuses in the overlap period between SPOT/VGT and PROBA-V (December 2013 to May 2014). Furthermore, it is complemented with statistics between PROBA-V and MODIS C5 surface albedo products for the whole 2014 year. Note that, in case of SPOT/VGT SA product, the version 1.5 was used as reference in the QAR, which was generated with Collection 3 SPOT/VGT input data, and calculated using the same algorithm as PROBA-V SA products (see 4.2). Note that Collection 3 is, among other changes, corrected from the error on the calculation of the sun-Earth distance that impacted the Collection 2 (Toté et al., 2017).

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 evaluated: product completeness, spatial consistency, temporal consistency, precision, a bulk statistical assessment of spatio-temporal consistency with similar products, and accuracy. The accuracy was computed against ground data coming from 17 SURFRAD and EFDC stations during the whole 2014 year.

PROBA-V and SPOT/VGT SA V1.5 products were found spatially and temporally consistent although it was found, in the near infrared (NIR) and shortwave (BB) domain, systematic positive biases and some unstable temporal profiles during the November 2013 to January 2014 period. Systematic positive bias (PROBA-V > SPOT/VGT) of ~5% was found for NIR and BB spectral channels over LANDVAL network of sites, with lower bias (<2%) for visible domain. The exception of positive bias was the snow pixels, where random sign of the bias was found. PROBA-V provides higher number of missing retrievals than SPOT/VGT (5%-10%), mainly observed over snow targets. In addition, the use of PROBA-V QFLAG (bit 6, input status; and bits 10-11, B2-B0 saturation status) removes most of the valid snow retrievals, so the use of the QFLAG is not recommended for snow applications. The comparison with MODIS over LANDVAL network of sites showed positive mean bias of ~5%, ~10% and~15% for visible, NIR and total shortwave. Similar intra-annual precision (smoothness) was observed between PROBA-V, SPOT/VGT and MODIS C5. Finally, the accuracy assessment against 17 SURFRAD and EFDC stations during the 2014 year (274 samples) showed RMSD of 0.042 and positive bias of 0.032 (22.1%). Only 4% of PROBA-V retrievals achieved the GCOS uncertainty requirements. Based upon these results, PROBA-V SA Collection 1km V1 product reaches validated stage 1 at the CEOS LPV hierarchy.

The main results of the Quality Assessment Report [CGLOPS1_VR_SA1km-PROBAV-V1.5] are summarized in Table 4.

Table 4: Summary of PROBA-V SA 2014 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 artefacts with the exception of a sharp latitudinal transition ~50º during winter season (due to known limitation of the PROBA-V cloud screening) Global distributions showed systematic positive bias (PROBA-V > SPOT/VGT) for NIR and BB, and bias 0 for VIS. Global distributions of residuals showed ~36% of cases within the optimal level for VIS, and 50% for NIR 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% (VIS 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 NIR.
Overall Spatio-Temporal Consistency	±	PROBA-V vs SPOT/VGT shows high correlation (R>0.93) and low scattering, with almost no mean bias in VIS and systematic positive mean bias of ~5% in NIR and BB (except in snow). 39%, 43% and 42% (67%, 73%, and 75%) of pixels showed optimal (target level) for VIS, NIR and BB. Comparison of PROBA-V and SPOT/VGT per biome type showed low bias (<3%, random sign) for VIS, and positive bias for NIR 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 VIS, NIR and BB, during the whole 2014 year. Percentage of pixels between the optimal (target) levels: 22% (46%), 21% (44%), and 7% (24%) for VIS, NIR and BB. Comparison of PROBA-V and MODIS C5 per biome type showed no systematic trend of the sign of bias for VIS, and positive bias for NIR 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.

4 SCIENTIFIC QUALITY EVALUATION METHOD

4.1 OVERALL PROCEDURE

The quality evaluation method follows the procedures described in the Global Land 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 (Fernandes et al., 2014).

The analysis was mainly focused on the comparison between recent PROBA-V V1 (2017 year) with the validated PROBA-V V1 (year 2014), and SPOT/VGT V1 (year 2012) products. This study covers the period during 1st of January to 31th of December 2017, and the equivalent period of the reference datasets was used as reference of quality in the analysis.

The following criteria of performance and metrics were assessed:

- **Product Completeness**

Completeness corresponds to the absence of spatial and temporal gaps in the data. Missing data are mainly due to cloud or snow contamination, poor atmospheric conditions or technical problems during the acquisition of the images, and is generally considered by users as a severe limitation of a given product. It is therefore mandatory to document the completeness of the product (i.e. the distribution in space and time of missing data). Global maps of missing values, distribution of gaps as a function of the season, and the length of the gaps are analyzed.

- **Spatial Consistency**

Spatial consistency refers to the realism and repeatability of the spatial distribution of retrievals over the globe. A first qualitative check of the realism and repeatability of spatial distribution of retrievals and the absence of strange patterns or artifacts (e.g., missing values, stripes, unrealistic low values, etc) can be achieved through systematic visual analysis of all maps based on the expert knowledge of the scientist. The methodology for visual analysis includes the visualization of zoom over sub-continental areas at full resolution (see 4.1.2 section), and the visualization of animations of global maps at a reduced (1/16 pixels) resolution.

- **Temporal Consistency**

The realism of the temporal variations over sites showing specific events during the 2017 year was evaluated, as well as over sites with available ground measurements from the NEON network. Furthermore, the temporal variations of the product under study are qualitatively analyzed as compared to reference validated products, and analyzed per biome types over the sub-continental area under study (see 4.1.2 section)

Globally, the consistency of temporal variations from the current period under study with reference products is investigated. The cross-correlation metric is included to quantitatively analyze the temporal consistency of the products. Cross-correlation is a standard method of estimating the degree to which two series are correlated. Consider two series x(i) and y(i) where i=0,1,2...N-1, the cross correlation ρ at delay d is defined as:

$$\rho = \frac{\sum_i[(x(i) - mx) \cdot (y(i-d) - my)]}{\sqrt{\sum_i(x(i) - mx)^2}\sqrt{\sum_i(y(i-d) - my)^2}}$$

where mx and my are the mean values of x and y series, respectively.

Histograms of cross correlation between recent (2017) and validated (2014) PROBA-V SA products temporal variations are analyzed per biomes over LANDVAL sites.

- **Precision**

Intra-annual precision

Intra-annual precision (smoothness) corresponds to temporal noise assumed to have no serial correlation within a season. In this case, the anomaly of a variable from the linear estimate based on its neighbours can be used as an indication of intra-annual precision or smoothness. It can be characterized as suggested by Weiss et al., (2007): for each triplet of consecutive observations, the absolute value of the difference between the center P(dn+1) and the corresponding linear interpolation between the two extremes P(dn) and P(dn+2) was computed:

$$\delta = \left| \mathbf{P}(\mathbf{d_{n+1}}) - \mathbf{P}(\mathbf{d_n}) - \frac{\mathbf{P}(\mathbf{d_n}) - \mathbf{P}(\mathbf{d_{n+2}})}{\mathbf{d_n} - \mathbf{d_{n+2}}}(\mathbf{d_n} - \mathbf{d_{n+1}}) \right|$$

Histograms of the smoothness are presented adjusted to a negative exponential function. The exponential decay constant is used as quantitative indicator of the typical smoothness value.

Inter-annual precision

Anomalies of an upper and lower percentile of variable are indicators of inter-annual precision (i.e., dispersion of variable values from year to year), (Fernandes et al., 2014). It can be assessed providing a box-plot of the median absolute deviation of anomalies versus product per bins. Note that Cultivated were not considered in this analysis due to the non-natural variability in these land cover types due to agricultural practices (e.g., crop rotation). Evergreen Broadleaved Forest sites were also not included due they are typically affected by cloud coverage.

In addition, scatter plots between two different years were generated over 20 desert calibration sites, and mean bias and RMSD values are also used as an indicator of the inter-annual precision of the products.

- **Overall Spatio-Temporal consistency**

The inter-comparison of products offers a means of assessing the discrepancies (systematic or random) between products. The global statistical analysis is performed over a global representative set of sites (LANDVAL) considering all the dates available. The LANDVAL network of sites was designed to represent globally the variability of land surface types (see 4.1.1). The spatio-temporal consistency was also performed at sub-continental scale (see 4.1.2 section).

The consistency between products under study and the reference products is further quantified based on uncertainties metrics associated to the scatter-plots between pairs of products (Table 6). The analysis is complemented with the distribution of products values in the form of PDFs and distribution of the residuals. These analyses are achieved per continents and per main land cover classes. Moreover, box-plots of uncertainty metrics (Bias and RMSD) per bin are also computed.

For the global analysis, box-plots of uncertainty metrics (Bias and RMSD) per bin are also presented. This analysis is complemented by the analysis of Probability Density Function (PDFs) and distribution of residuals per biomes and continents. The sub-continental was also achieved by scatter plots and boxplots of uncertainty metrics (Bias and RMSD) per aggregated land cover class.

The residuals (ε) are estimated assuming a linear trend between two products ($Y = a X + b + \varepsilon$), then the residual can be written as $\varepsilon = Y - a X - b$, which represent the remaining discrepancies regarding the general trend between both products. In this way, systematic trends are not considered, depicting more clearly patterns associated to the spatial distribution of retrievals. The linear trend has been computed using LANDVAL sites for the period under study.

Two main levels of uncertainty (optimal and target) were defined, as described in Table 5. The percentage of pixels within these uncertainty levels is quantified. The optimal level (Max [5%, 0.0025]) was selected according to the GCOS uncertainty requirement (Table 1), and the target level (Max [10%, 0.005]) is partly equivalent to the CGLOPS optimal level (Table 2) and WMO breakthrough level (10%, see Table 3). An additional threshold level (0.02 for SA < 0.15 and 20% for SA > 0.15) was defined (equivalent to CGLOPS Target - Table 2), so poor uncertainties correspond to values above this level. Figure 1 displays the selected uncertainty levels as a function of the product values. Based upon these levels, for surface albedo values lower than 0.05, absolute uncertainty levels of 0.0025, 0.005 and 0.0075 (optimal, target and threshold) are used. For surface albedo values higher than 0.05, relative values of 5%, 10% and 15% are used.

Table 5: Uncertainty levels used for SA products.

	Optimal	Target	Threshold
white-sky and black-sky albedo	Max [5%, 0.0025]	Max [10%, 0.005]	- 0.03 for SA<0.15 - 20% for SA>0.15

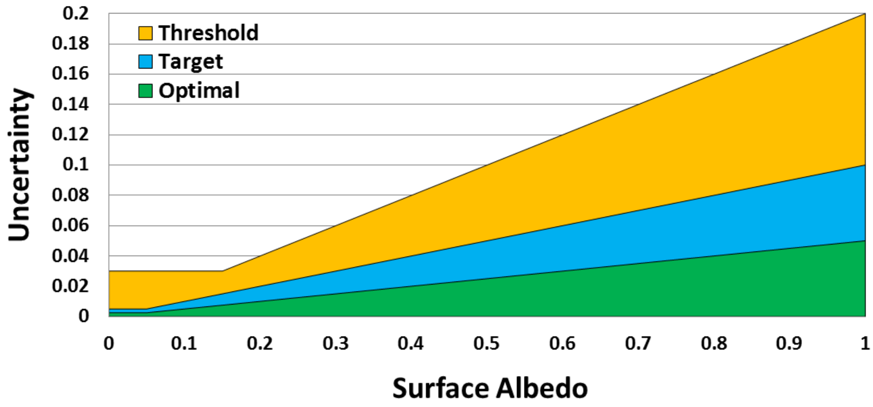


Figure 1: Uncertainty levels as a function of SA values.

- **Accuracy Assessment**

Accuracy is quantified by several metrics reporting the goodness of fit between the products and the corresponding ground measurements (Table 6). Total measurement uncertainty (i.e., root mean square deviation, RMSD) includes systematic measurement error (i.e. Bias) and random measurement error (i.e., Standard deviation of bias). RMSD corresponds to the accuracy as there is only one product estimate for each mapping unit and date (Fernandes et al., 2014). RMSD is recommended as the overall performance statistic. Linear model fits are used to quantify the goodness of fit. For this purpose, Major Axis Regression (MAR) were computed instead Ordinary Least Squares (OLS) because it is specifically formulated to handle error in both of the x and y variables (Harper, 2014).

Table 6: Uncertainty metrics for product validation

Gaussian Statistics	Comment
N: Number of samples	Indicative of the power of the validation
RMSD: Root Mean Square Deviation	RMSD is the square root of the average of squared errors between x and y. Indicates the Accuracy (Total Error). Relative values between the average of x and y were also computed.
B: Mean Bias	Difference between average values of x and y. Indicative of accuracy and possible offset. Relative values between the average of x and y were also computed.
S: Standard deviation	Standard deviation of the pair differences. Indicates precision.
R: Correlation coefficient	Indicates descriptive power of the linear accuracy test. Pearson coefficient was used.
MAR: Major Axis Regression (slope, offset)	Indicates some possible bias.
% uncertainty levels	Percentage of pixels matching the optimal, target and threshold uncertainty levels.

Main steps in accuracy assessment of albedo products include generation of blue-sky albedo (Lewis and Barnsley, 1994) for direct comparison with in situ measurements and test of spatial representativeness of in situ albedometer footprints for satellite pixel resolution of interest according to in situ measurements standards (Roman et al., 2010). As a consequence, a careful selection of ground points and the characterization of their spatial representativeness are crucial for a meaningful point-to-pixel comparison. Then, for direct comparison with the satellite product, the site should be spatially representative of the kilometric resolution (i.e. spatial resolution of the product under study). Only homogeneous sites at $1km^2$ were selected for accuracy assessment (see section4.3).

- **Summary of Scientific Quality Evaluation Procedure**

The analysis was focused on the comparison between recent PROBA-V SA products (2017) with reference validated PROBA-V period (2014, see CGLOPS1_VR_SA1km-PROBAV-V1.5), and with SPOT/VGT SA V1 during the 2012 year (GIOGL1_VR_SAV1). Furthermore, NASA MCD43A3 C6 is used for benchmarking for the accuracy assessment against ground data, and for the temporal trend over specific fire events. Two spatial domains in terms of coverage (global and regional) have been considered. Summary of global analysis is showed in Table 7 and summary of regional analysis is showed in Table 8.

Table 7: Summary of the quality criteria for global analysis

Quality Criteria	Product Evaluated	Reference Product	Coverage
Completeness	PROBA-V V1 2017	PROBA-V V1 2014 SPOT/VGT 2012	Global LANDVAL
	-Global Gap distribution (average maps and temporal variation). -Length of gaps over LANDVAL.		
Spatial Consistency	PROBA-V V1 2017	PROBA-V V1 2014	Global
	-Visual Inspection of Global maps		
Temporal Consistency	PROBA-V V1 2017	PROBA-V V1 2014	LANDVAL
	-Histograms of Cross-correlation		
Inter-annual Precision	PROBA-V V1 2017	PROBA-V V1 2014	LANDVAL
	-Box-plot per bin and median absolute anomaly of 95^{th} percentile and 5^{th} percentile. -Scatter-plots and associated metrics between two different years (calibration sites).		
Intra-annual Precision (smoothness)	PROBA-V V1 2017	PROBA-V V1 2014 SPOT/VGT 2012	LANDVAL
	-Histograms of the smoothness		
Overall Spatio-Temporal consistency	PROBA-V V1 2017	PROBA-V V1 2014 SPOT/VGT 2012	LANDVAL
	-Scatter-plots (R, RMSD, Bias, Scattering, Major Axis Regression). Percentage of differences between the different uncertainty levels. -Box-plots of uncertainties statistics (Bias and Absolute Bias) per bin. -PDFs of retrievals & histograms of residuals per biome.		

Table 8: Summary of the quality criteria for the Regional Analysis

Quality Criteria	Product Evaluated	Reference Product	Coverage
Spatial Consistency	PROBA-V V1 2017	PROBA-V V1 2014	West-Africa
	-Visual inspection sub-continental regional maps.		
Temporal Consistency	PROBA-V V1 2017	MCD43A3 C6 PROBA-V V1 2014	Specific fire events Ground reference stations West-Africa
	-Qualitative inspection of temporal variations over locations with fire events and availability of ground data. -Mean average of temporal variations per biome types over West-Africa		
Statistical Consistency	PROBA-V V1 2017	PROBA-V V1 2014	West-Africa
	-Box-plots of uncertainty metrics (Bias and RMSD) per biomes		
Accuracy Assessment (Error)	PROBA-V V1 MCD43A3 C6	Ground data	Ground reference stations

The following Quality Flag information was used to filter pixels flagged as out of range, saturated or invalid (Table 9) for the spatio-temporal consistency and accuracy assessment of SA Collection 1km V1 product. In case of MODIS C6, the quality ancillary information of the product is provided in a separate product (MCD43A2). MODIS 'full inversion' pixels were considered as 'good quality', and 'magnitude inversion' pixels with number of valid observations lower than 7 or fill values were rejected.

Table 9: Quality Flag information used to filter low quality or invalid pixels.

Product	QualityFlag
PROBA-V & SPOT/VGT V1	Sea (**bit 1**) Input status out of range or invalid (**bit 6**) B2 saturated (**bit 10**) B0 saturated (**bit 11**)
MCD43A2 C6	BRDF_Albedo_Band_Quality_Band1-7 '3' = Magnitude inversion (numobs >=2&<7) '4' = Fill value

4.1.1 Global analysis: LANDVAL Network

The LANDVAL network of 725 sites (Figure 2) was used for inter-comparison. This network is composed with 521 sites coming from SAVS 1.0 (Surface Albedo Validation Sites) network (Loew et al., 2016), available at http://savs.eumetsat.int. SAVS 1.0 was created during the ALBEDOVAL-2 study (Fell et al., 2015), in the framework of QA4ECV (Quality Assurance for Essential Climate Variable) project. In addition, 20 sites (*'calibration sites'*) in the Sahara Desert and Arabia desert are included in order to increase the sampling over desertic areas and African region. These reference sites, well known for their high temporal stability, are used by CNES for the absolute calibration of remote sensing sensors. Finally, 184 sites coming from existing (e.g. ImagineS (http://fp7-imagines.eu/), AsiaFlux , NARMA or OzFlux) networks or Geo-Wiki platform (http://www.geo-wiki.org/) were included in order to cover under sampled regions (Asia, Africa, Oceania) and biome types (Shrub, deciduous broadleaf forest (DBF), needle leaf forest (NLF)).

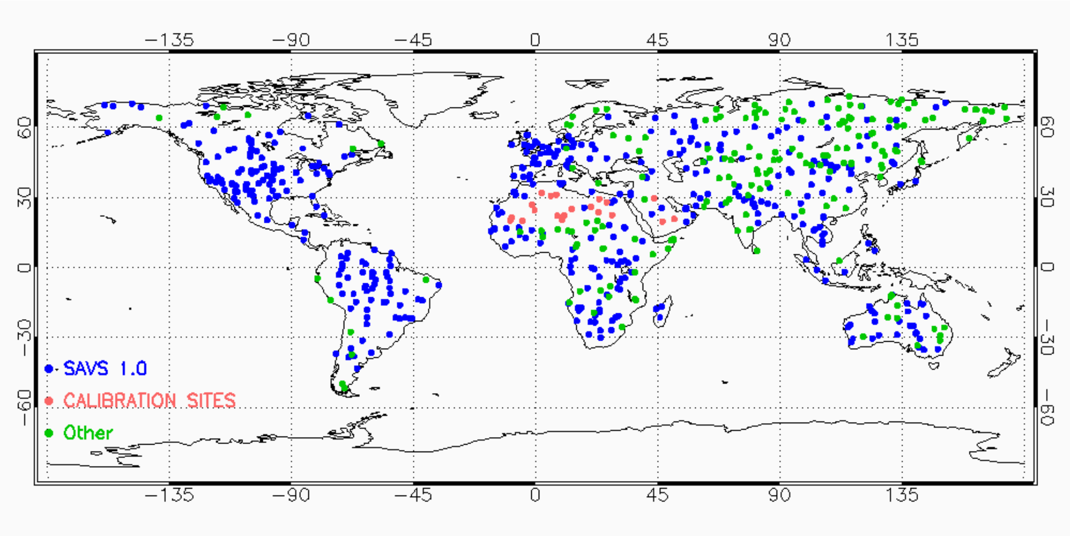


Figure 2: Global distribution of the selected LANDVAL sites.

The methodology for the selection of sites is described in the validation report of PROBA-V SA [CGLOPS1_VR_SA1km-PROBAV-V1.5]. The selection criteria that have been chosen for each LANDVAL site are showed in Table 10.

Table 10: Criteria of selection of sites coming from SAVS 1.0

Parameter	Threshold	Purpose
Distance to open water bodies [km]	5	Avoid open water bodies and their changing reflectance behavior with viewing geometry
Minimum fraction of majority land cover type at 5 km distance	60%	Avoid areas with heterogeneous land cover.
Land Cover Majority at 5km	Exclude 'Water bodies' and 'Urban areas'	
Vertical range [m] within a distance of 5km	<300m	Avoid areas with significant terrain variability close to a site.
Location (Latitude)	60ºS to 80ºN	Exclude sites over extreme latitudes, where Global Land products does not provide data

The 725 LANDVAL sites were classified according to the main biome type as well as per continents to assess the product performance per regions and biomes (Figure 3). The main biome are obtained aggregating similar land cover classes from the GLC2000 classification (Bartholome and Belward, 2005): Evergreen Broadleaf Forest (EBF), Deciduous Broadleaf Forest (DBF), Needle leaf Forest (NLF), Shrublands (S), Herbaceous (H), Cultivated (C), Sparse and Bare areas (BA).

The regional analysis is made per continental regions as defined in the Copernicus Global Land Service. The six continental regions are: North America (NOAM), South America (SOAM), Europe (EURO), Africa (AFRI), Asia (ASIA) and Oceania (OCEA) (Figure 3).

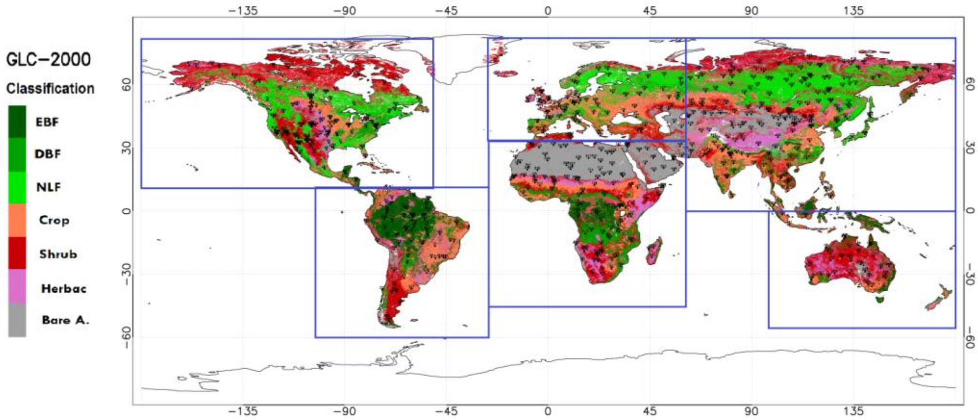


Figure 3: Location of the LANDVAL sites over an aggregated land cover (GLC-2000) map. Blue squares correspond to the six continental regions.

4.1.2 Sub-Continental Regional analysis

4.1.2.1 West-Africa Region

Figure 4 show maps of the aggregated land cover types from GLC-2000 (Bartholome and Belward, 2005) for the selected region over West-Africa for the sub-continental regional analysis. This region (window size of 21º latitude and 43º of longitude) was selected due to interest of Copernicus Global Land users.

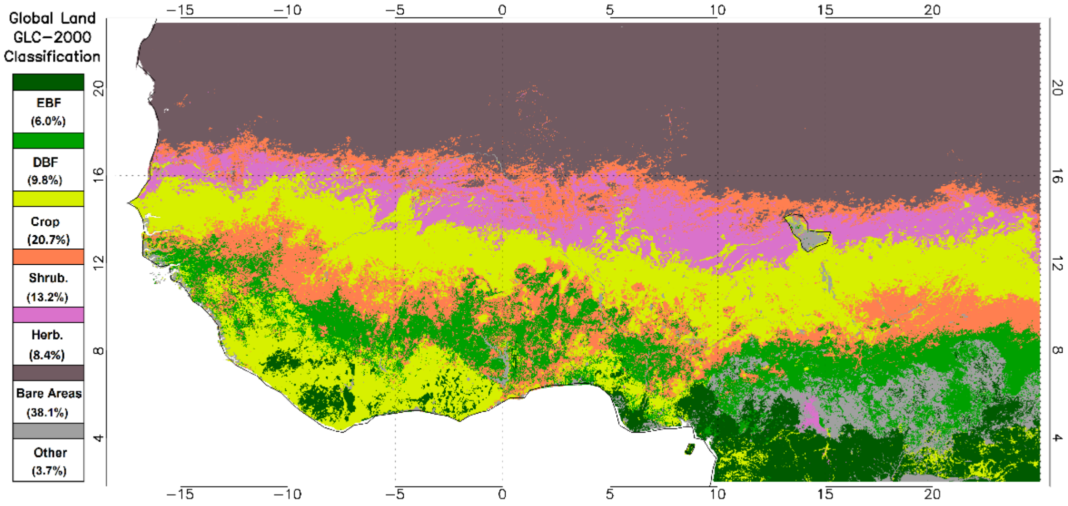


Figure 4: Map of aggregated land cover from GLC-2000 over the West African window. All the classes are aggregated in the following main biomes (up to down in the legend): Broadleaved Evergreen Forest, Broadleaved Deciduous Forest, Croplands, Shrublands, Herbaceous, Bare Areas and Other.

The percentage of land pixels per main biome are: Bare Areas (38.1%), Croplands (20.7%), Shrublands (13.2%), Deciduous Broadleaved Forest (9.8%), Herbaceous (8.4%) and Evergreen Broadleaved Forest (6.0%).

4.1.2.2 Specific fire events

Five specific fire events (Table 11) have been selected to evaluate the realism of the PROBA-V SA temporal variations. Two main sources were used to identify these events:

- The NASA Earth Observatory whose mission is to share with the public the images, stories, and discoveries about climate and the environment that emerge from NASA research, including its satellite missions, in-the-field research, and climate models.
- The European Forest Fire Information System (EFFIS) has been established by the European Commission (EC) in collaboration with the national fire administrations to support the services in charge of the protection of forests against fires in the EU and neighbor countries, and to provide the EC services and the European Parliament with harmonized information on forest fires in Europe. (http://effis.jrc.ec.europa.eu). Also note that in 2015, EFFIS became one of the components of the Emergency Management Services in the EU Copernicus program.

Table 11: Main characteristics of the selected specific fire events.

Site	Country	Lat (°)	Long (°)	Event	Date (yyyy/mm)
Chile	Chile	-35.470722	-72.281126	Fire	2017/01
Argentina	Argentina	-39.883590	-63.794014	Fire	2017/01
Siberia	Russia	58.352761	106.130601	Fire	2017/06
Pedrógão Grande	Portugal	39.927674	-8.209448	Fire	2017/06
California	USA	34.372792	-119.215963	Fire	2017/12

4.2 SATELLITE REFERENCE PRODUCTS

- **PROBA-V Collection 1km Version 1.5 (PROBA-V V1)**

The SA V1.5 algorithm applied on PROBA-V input reflectances is described in the ATBD of PROBA-V SA product [CGLOPS1_ATBD_SA1km-V1]. It follows the approach separating atmospheric correction, directional reflectance normalization, and albedo determination. First, the top-of-atmosphere (TOA) data is processed in order to get cloud-free top-of-canopy (TOC) reflectances. Then, the spectral TOC reflectances acquired under different solar-viewing configurations during the synthesis period are normalized by inversion of the Roujean et al., (1992) linear kernel-driven model. The synthesis period is 30-days and a semi-gaussian weighting function with the maximum weight on the last observation of the period was selected for near real time production. Then the spectral albedos are computed by the angular integration of kernel functions with the retrieved parameters for each pixel. Finally, the broadband albedo is defined as a linear combination of the spectral albedos values in the available spectral channels. The narrow to broadband conversion coefficients are applied both for the directional-hemispherical albedo and for the bi-hemispherical albedo. They are generated from the Collection 1 PROBA-V input data [PUM_PROBA-V-C1].

Apart of the layers corresponding to the directional (AL-DH) and the bi-hemispherical (AL-BH) albedos in visible, NIR and total spectrum, the ancillary layers corresponding to their respective errors (ERR), the associated Quality Flag (QFLAG) and the number of valid observations during the synthesis period (NMOD) are provided. The information of each layer is described in the Product User Manual [GLOPS1_PUM_SA1km-V1].

The review of the validation results of the version 1.5 of PROBA-V Collection 1km V1 is provided in Chapter 3.

- **SPOT/VGT Collection 1km Version 1.4 (SPOT/VGT V1)**

The SPOT/VGT SA V1 product (Version 1.4), available in the product distribution portal (https://land.copernicus.vgt.vito.be/PDF/), was used as reference in the current exercise. This version was generated with Collection 2 of SPOT/VGT input data with incorrect implementation of the sun-Earth distance, and the period used in this study is the 2012 year. SPOT/VGT SA V1 products are calculated using the same algorithm as the evaluated PROBA-V SA V1.5 products [CGLOPS1_ATBD_SA1km-V1], except for specific set of narrow-to-broadband coefficients in the case where snow is detected, and also considering the cases when the B0 (blue) and B3 (near-infrared) bands are saturated.

The validation exercise of SPOT/VGT albedo products [GIOGL1_VR_SAV1] demonstrated that SPOT/VGT albedo V1.4 products are comparable to that of MODIS C5 (best quality) albedo products, except for Snow/Ice pixels. As compared with MODIS, small biases were observed for all biomes (except for snow) with an overall consistency for the shortwave albedo quantities (AL-DH, AL-BH) of about 0.03 (13%) in term of RMSD for all BELMANIP2 pixels, and of about 0.02 (10%) for snow-free pixels. Temporal profiles were 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 comparison with field data for FLUXNET homogeneous sites showed a RMSD of about 0.05 and albedo underestimation for mixed snow/vegetation pixels. The accuracy (RMSD) for snow-free values was 0.03 with a slight positive mean bias of SPOT/VGT albedo of only 0.005.

- **NASA Terra+Aqua MODIS BRDF/Albedo**

The MODIS BRDF/Albedo MCD43A3 collection 6 (https://doi.org/10.5067/MODIS/MCD43A4.006) is a daily 16-day product, available since 2000 from https://lpdaac.usgs.gov. The Julian date in the granule ID of each specific file represents the 9^{th} day of the 16 day retrieval period, and consequently the observations are weighted to estimate the reflectance value for that day.

The MCD43A3 algorithm, as is with all combined products, chooses the best representative pixel from a pool that includes all the acquisitions from both the Terra and Aqua sensors from the retrieval period. The product is derived using a kernel-driven semi-empirical BRDF model, utilizing the Ross Thick-Li Sparse kernel functions for characterizing isotropic, volume and surface scattering (Lucht et al., 2000; Wanner et al., 1997). The detailed retrieval algorithm, including the atmospheric correction, is described in Schaaf et al. (2002) and Schaaf et al. (2011). The MCD43A3 provides both directional hemispherical reflectance (black sky albedo) and bihemispherical reflectance (white sky albedo) from 500 meter data for each of the MODIS bands 1 through 7, as well as for three broad-bands (visible: 0.3-0.7µm, NIR: 0.7-5.0µm, and Total: 0.3-5.0µm). Along with the albedo layers are the Mandatory Quality layers for each of the 10 bands.

The MODIS BRDF/ALBEDO products have achieved the validation stage 3 according to CEOS LPV hierarchy. The quality of MCD43 products was investigated by analyzing the albedo product. The accuracy of the high quality MODIS operational albedos at 500m is well less than 5% albedo at the majority of the validation sites studied (Salomon et al., 2006; Shuai et al., 2008).

The subsets of MCD43A3 products over the sites under study were obtained using the MODIS Collection 6 Land Products Global Subsetting Tool at the ORNL DAAC (https://doi.org/10.3334/ORNLDAAC/1379).

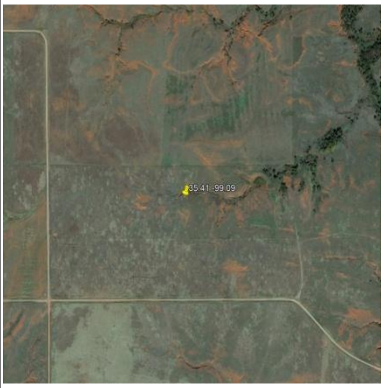
4.3 IN-SITU REFERENCE PRODUCTS

The accuracy of PROBA-V SA V1.5 Albedo products was estimated against ground reference data coming from NEON stations (https://www.neonscience.org/). The accuracy of MODIS C6 was also estimated for benchmarking. To guarantee the highest level of homogeneity and to minimize issues associated with spatial representativeness in the point-to-pixel comparison, only homogeneous sites were considered (Cescatti et al., 2012). The land cover characteristics of the sites have been carefully classified using high resolution satellite images (available via Google Earth™), to identify those matching the requirement of homogeneity in the area surrounding the measurement tower (Román et al., 2009, 2010). The classification has been performed at 1 km^2 resolution, taking into account the spatial resolution of PROBA-V surface albedo V1.5 products.

The NEON ground data was made available daily, providing up-welling and down-welling shortwave radiation, as well as the direct and diffuse shortwave radiation information. The comparison is carried out by compositing the daily field data at noon over the compositing period of the satellite products. The different temporal compositing weighting scheme was considered for each product (30 days for PROBA-V and 16 days for MODIS). A composite value is obtained when more than 70% of daily ground measurements are available. For the accuracy assessment the "blue-sky" albedo was estimated from the black-sky (AL-DH-BB) and white-sky (AL-BH-BB) albedo products weighted by the fraction of direct and diffuse down-welling shortwave radiation, respectively (Lewis and Barnsley, 1994).

Table 12 shows the 5 homogeneous sites with ground albedo data over different biomes used in this study. The high-resolution images (available via Google Earth™) used to evaluate the site homogeneity at 1km^2 are also shown.

Table 12: NEON sites providing field albedo measurements and Google Earth views at 1km².

Site	Google Earth™ view at 1km²	Land Cover	Lat (deg)	Lon (deg)
Klemme ange - Oklahoma (USA)		Herbaceous	35.41	-99.09
Ordway Swisher - Florida (USA)		Forest	29.69	-81.999
Onaqui Ault - Utah (USA)		Shrublands	40.18	-112.45

Oak Ridge - Tennessee (USA)		Forest	35.96	-84.28
Smithsonian - Virginia (USA)		Forest	38.89	-78.14

5 RESULTS

5.1 GLOBAL ANALYSIS

5.1.1 Product Completeness

Global map of the percentage of missing values during the 2017 year of PROBA-V SA product is displayed in Figure 5 for black-sky albedo in shortwave domain. The information from the Quality Flag was not considered here in the computation of gaps.

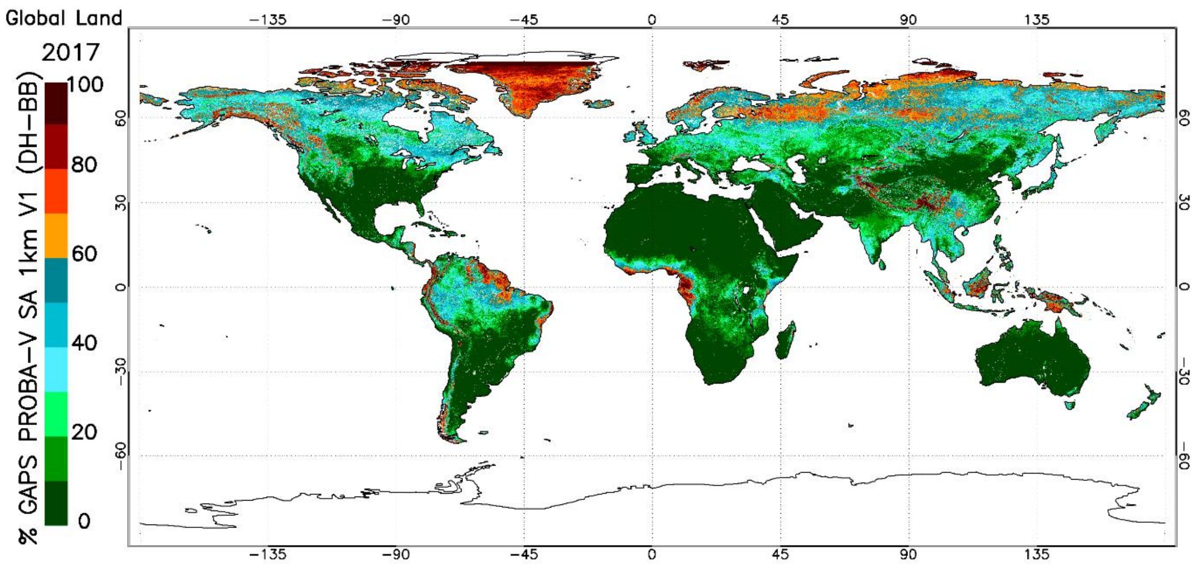


Figure 5: Percentage of missing values during the 2017 year for PROBA-V SA Collection 1km V1 (AL-DH-BB) product considering all land pixels.

The main conclusions are:

- The spatio-temporal continuity of PROBA-V SA products is poor over latitudes higher than 45º North and over the equatorial belt, with a percentage of missing values up to 100% in some pixels over these areas, which is explained by the lack of clear-sky observations. These results are consistent with the previous validation results [CGLOPS1_VR_SA1km-PROBAV-V1.5], where similar maps of missing data were found for year 2014.
- Almost identical results were found for both black-sky and white-sky albedos in all spectral ranges.

Figure 6 shows the temporal evolution of missing values for PROBA-V SA products during the 2017 and 2014 for the AL-DH-BB. The information coming from the QFLAG was not used here.

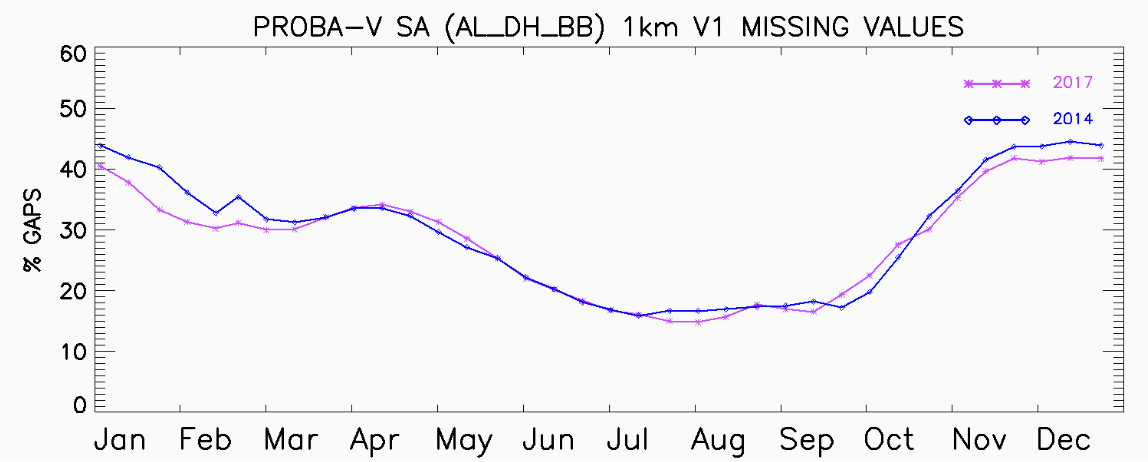


Figure 6: Temporal variations of missing values for PROBA-V SA V1 product during the 2014 (blue line) and 2017 (purple line) year for AL-DH-BB.

The main conclusions from Figure 6 are:

- Globally, PROBA-V provides similar fraction of missing data between 2017 and 2014, with some differences only during winter period, where slight better fraction of valid retrievals was found for 2017.
- Similar trend was observed between both black-sky and white-sky albedos in all spectral channels, showing almost identical number of missing data, which is consistent with the previous validation results [CGLOPS1_VR_SA1km-PROBAV-V1.5].

Figure 7 shows the distribution of the temporal length of gaps of PROBA-V SA (2017 and 2014 years) and SPOT/VGT SA (2012 year) black-sky albedo products in all spectral channels, with aim to better understand the impact of the gaps for monitoring the temporal variations. The computation was done over LANDVAL sites.

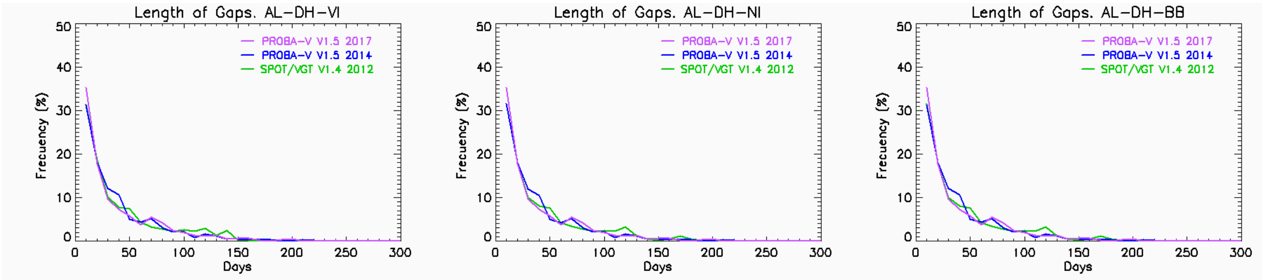


Figure 7: Distribution of the temporal length of the missing values over LANDVAL sites during the 2017 and 2014 years for PROBA-V SA and during the 2012 for SPOT/VGT SA products for AL-DH-VI (left), AL-DH-NI (middle) and AL-DH-BB (right).

As shown in Figure 7:

- Similar distribution of the length of gaps was found between recent (2017) and reference PROBA-V 2014 and SPOT/VGT 2012 years. In all cases, around 35% of gaps correspond to only one missing dekad, and around 65% of the gaps are shorter than 3 dekads (i.e. one month of data).
- Similar distribution of the length of gaps was found between the different spectral bands, and between black-sky and white-sky retrievals.

5.1.2 Spatial Consistency

5.1.2.1 Visual inspection of global maps

Global maps of 2017 PROBA-V SA products were displayed at 1/16 of its original resolution and visually compared with equivalents maps of the validated 2014 year. Some examples are shown from Figure 8 to Figure 13.

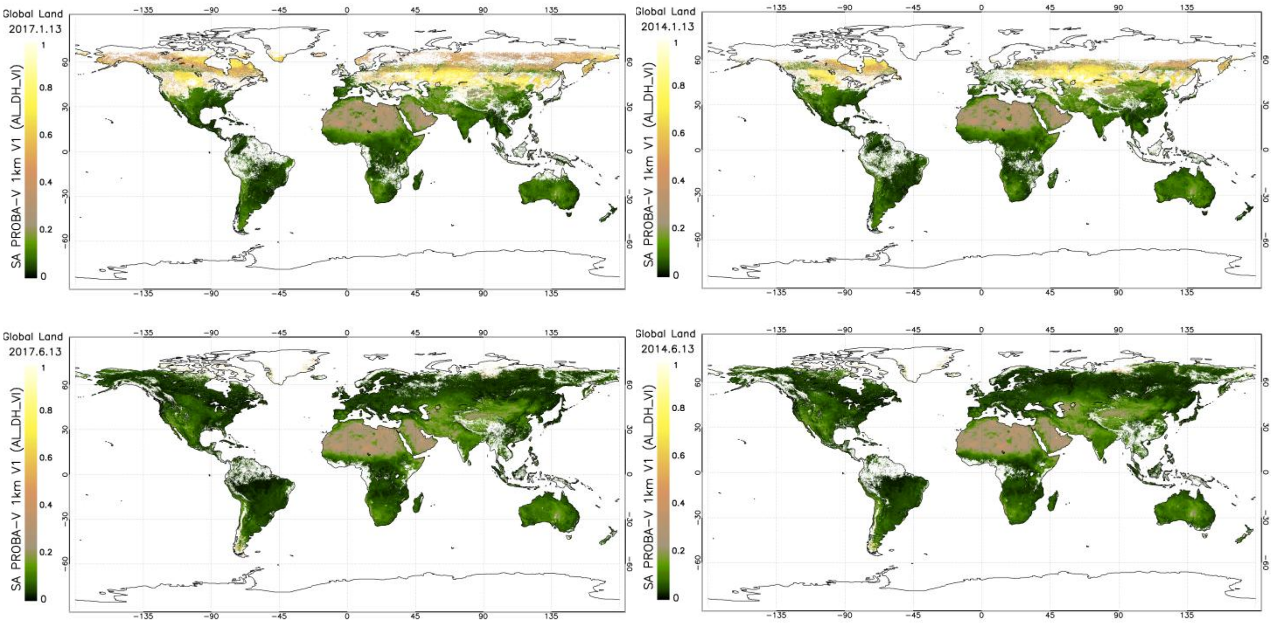


Figure 8: PROBA-V SA (AL-DH-VI) global maps for mid of January (Top) and mid of July (Bottom) for 2017 (left) and 2014 (right).

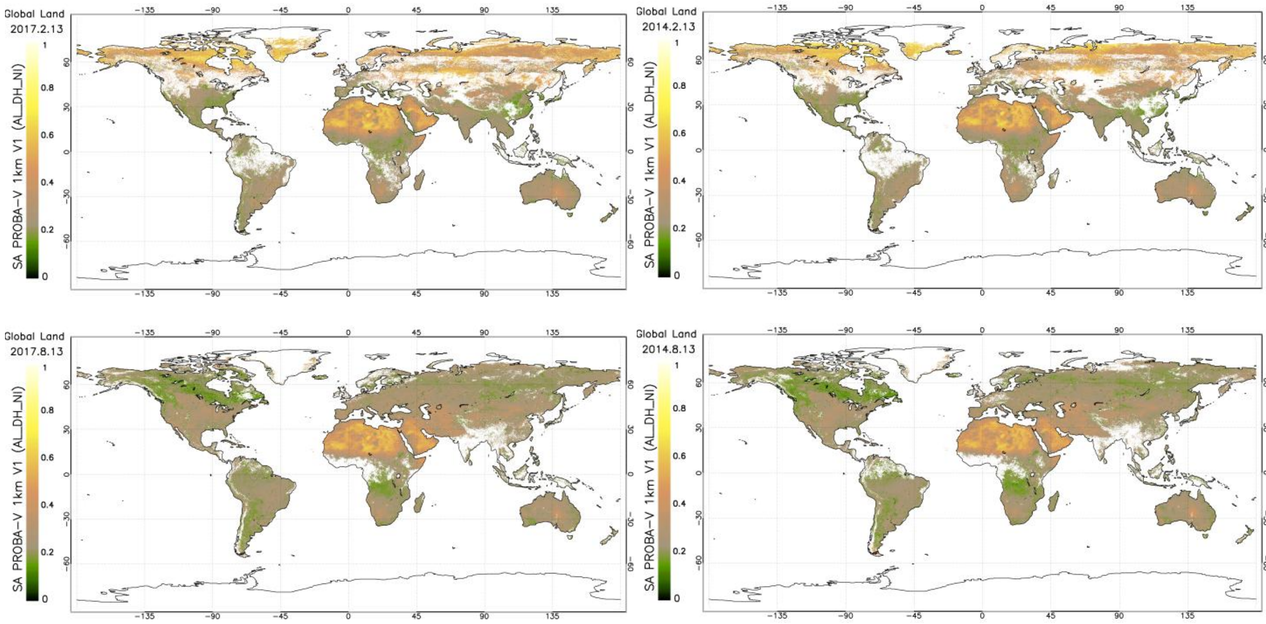


Figure 9: PROBA-V SA (AL-DH-NI) global maps for mid of February (Top) and mid of August (Bottom) for 2017 (left) and 2014 (right).

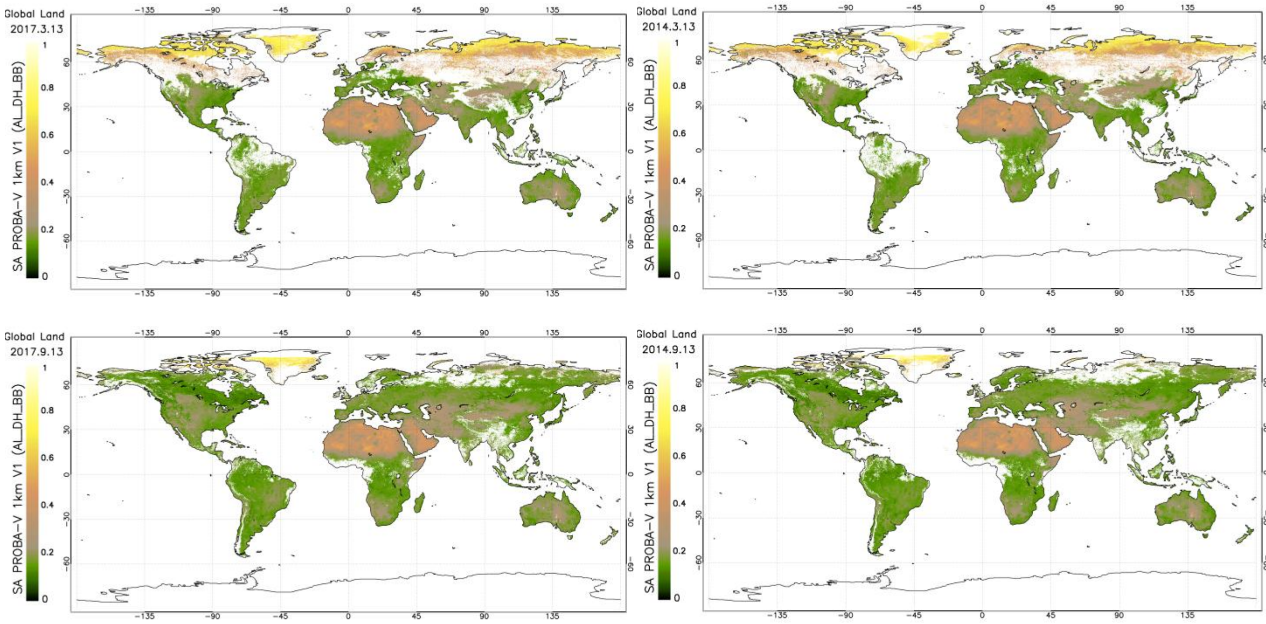


Figure 10: PROBA-V SA (AL-DH-BB) global maps for mid of March (Top) and mid of September (Bottom) for 2017 (left) and 2014 (right).

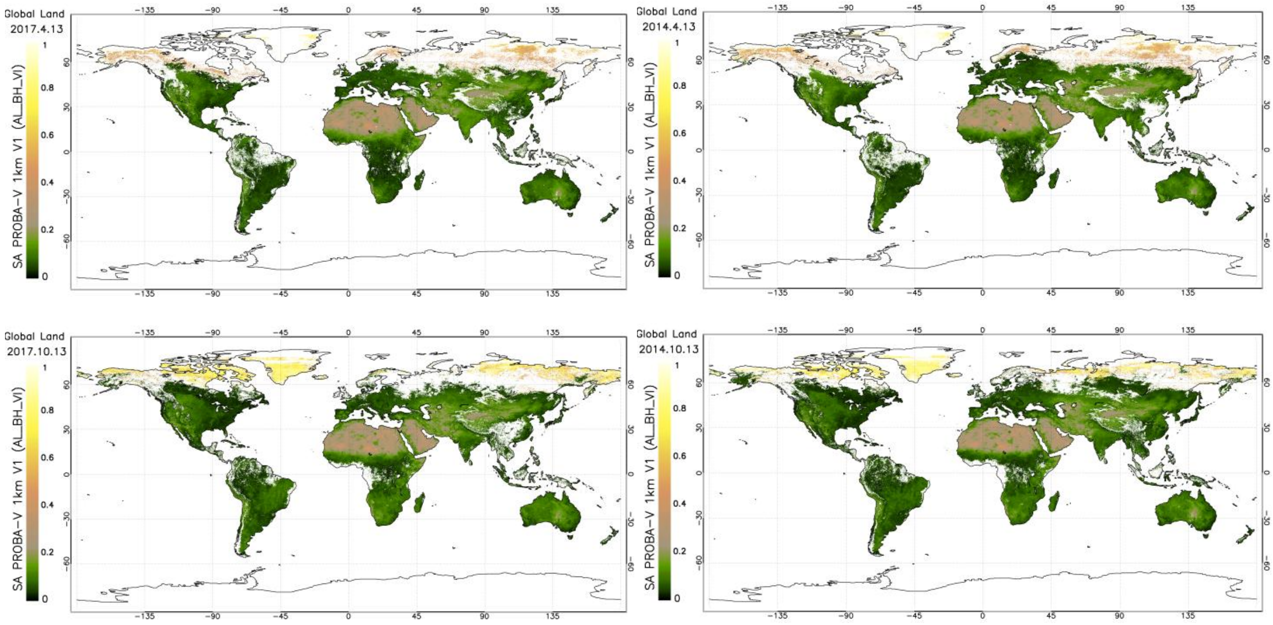


Figure 11: PROBA-V SA (AL-BH-VI) global maps for mid of April (Top) and mid of October (Bottom) for 2017 (left) and 2014 (right).

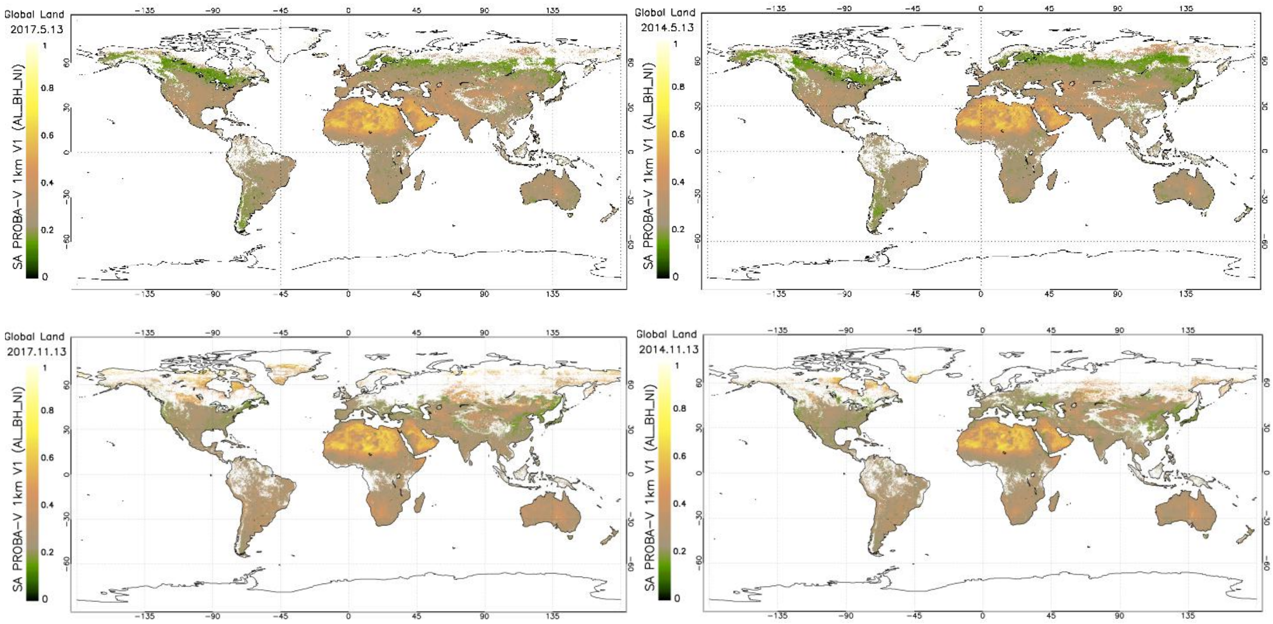


Figure 12: PROBA-V SA (AL-BH-NI) global maps for mid of May (Top) and mid of November (Bottom) for 2017 (left) and 2014 (right).

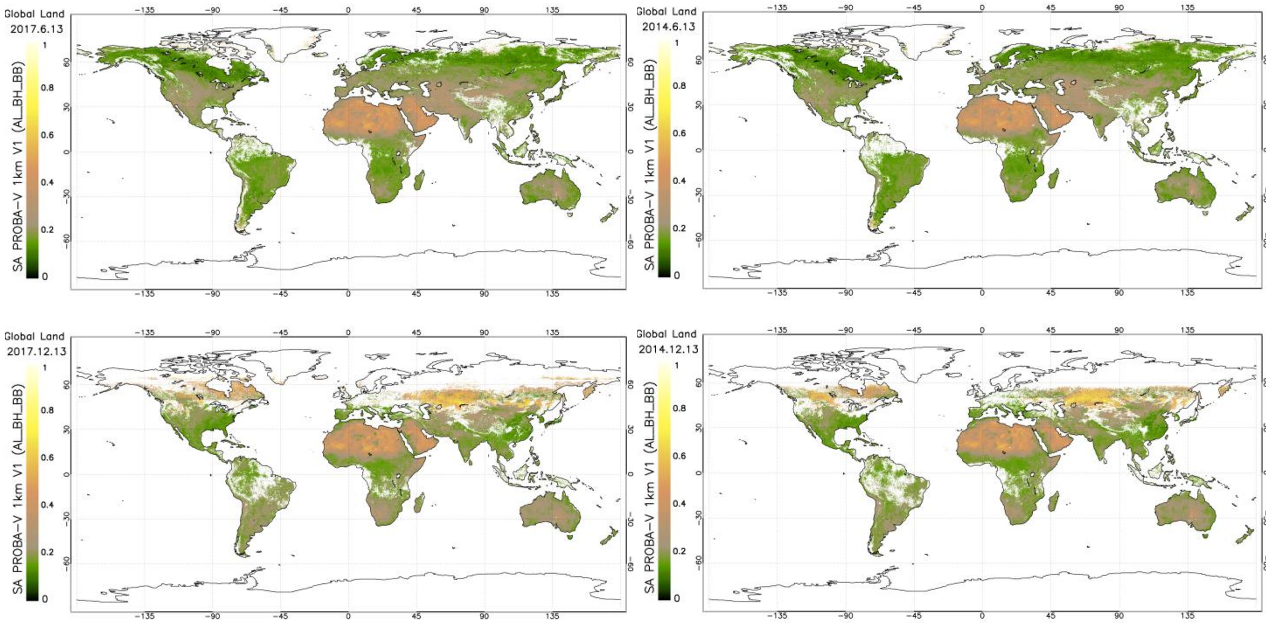


Figure 13: PROBA-V SA (AL-BH-BB) global maps for mid of June (Top) and mid of December (Bottom) for 2017 (left) and 2014 (right).

Main findings are:

- As observed at the global maps, consistent distribution of values was generally found between recent (2017) and validated (2014) products, without finding suspicious patterns for all the dates.
- Sharp latitudinal transitions over northern hemisphere (around ~50º and/or ~65º) were observed during winter time in northern hemisphere, in line to that found in the PROBA-V SA validation report [CGLOPS1_VR_SA1km-PROBAV-V1.5]. This pattern is the consequence of a known limitation (http://proba-v.vgt.vito.be/en/quality/cloud-detection-issues) of the PROBA-V cloud detection algorithm [see product_user_manual.pdf].

5.1.3 Temporal Consistency Analysis

5.1.3.1 Cross-Correlation distributions

Figure 14 and Figure 15 show the AL-DH and AL-BH cross-correlation distributions of temporal variations between recent (2017) and validated (2014) PROBA-V SA products for visible, NIR and shortwave spectral channels per biome type, computed over LANDVAL sites during the January to December period.

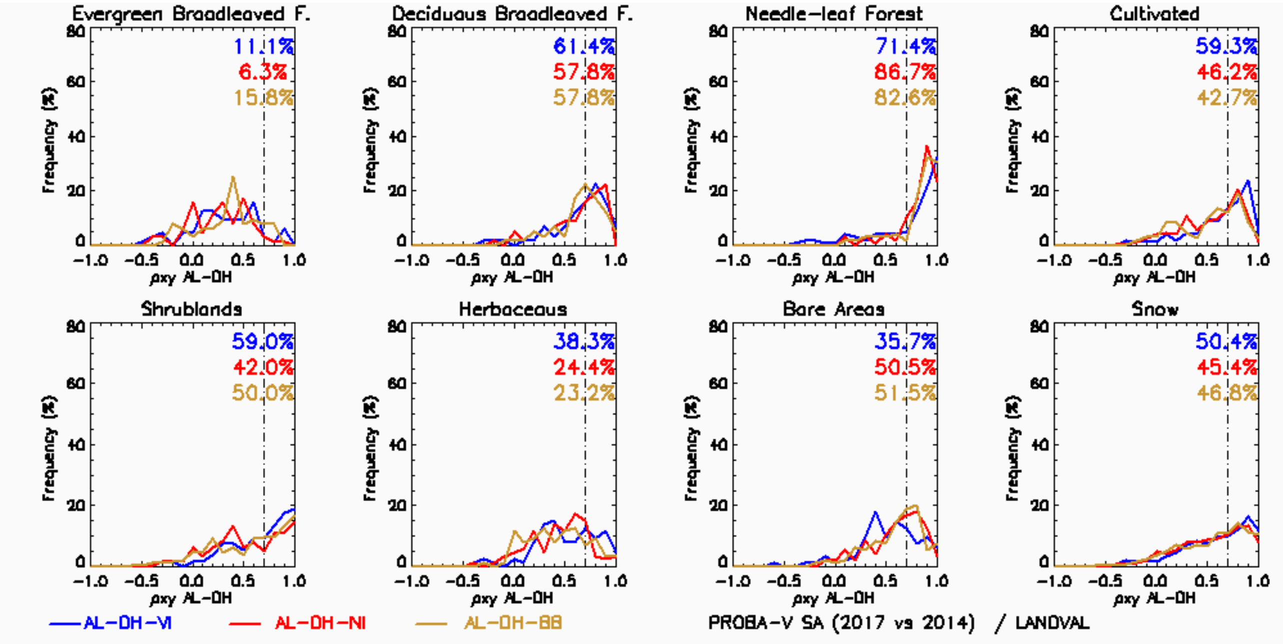


Figure 14: AL-DH cross-correlation distributions (ρ_{XY}) between PROBA-V SA 2017 and 2014 years for LANDVAL sites for each main biome type. The values in each plot shows the percentage of cases with correlations higher than 0.7.

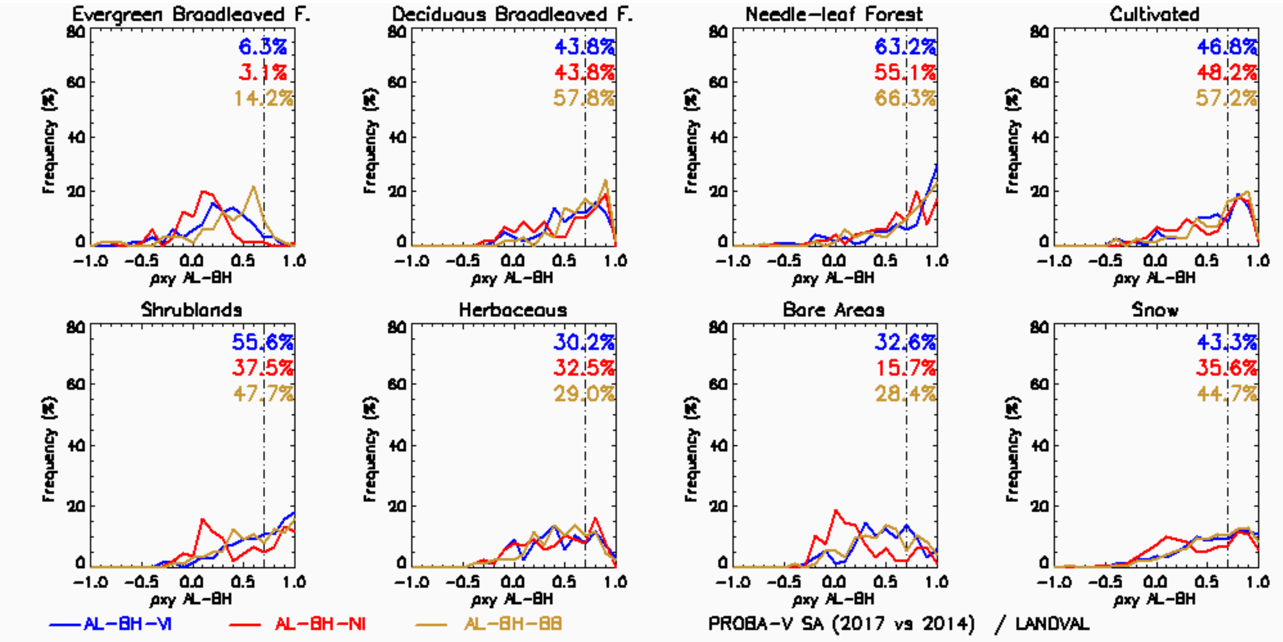


Figure 15: AL-BH cross-correlation distributions (ρ_{XY}) between PROBA-V SA 2017 and 2014 years for LANDVAL sites for each main biome type. The values in each plot shows the percentage of cases with correlations higher than 0.7.

Main findings are:

- For AL-DH-VI, cross-correlations were higher than 0.7 typically in more than 40% of cases for most of the biome cases, with the exception of Herbaceous and Bare Areas. Poor cross-correlations were found for EBF.
- Similar results were found for AL-DH-NI and AL-DH-BB, with cross-correlations higher than 0.7 typically in more than 40% of cases for most of the biomes (except for Herbaceous), and showing poor cross-correlations in EBF.
- Lower cross-correlation between 2017 and 2014 PROBA-V SA temporal profiles were found for white-sky albedos compared to black-sky albedos.

5.1.4 Inter-Annual precision

5.1.4.1 Absolute inter-annual anomalies

Box-plots per bin value of absolute inter-annual anomalies of PROBA-V recent products (2017) as compared to PROBA-V validated (2014) SA products are analyzed, and displayed in Figure 16. Note that these results are evaluated for black-sky albedos, and very similar results were found for white-sky albedos. The computation was performed using the upper 95th and lower 5th percentiles over all LANDVAL sites with the exception of croplands and EBF, and the median of the absolute anomaly is proposed as indicator of inter-annual precision (Fernandes et al., 2014).

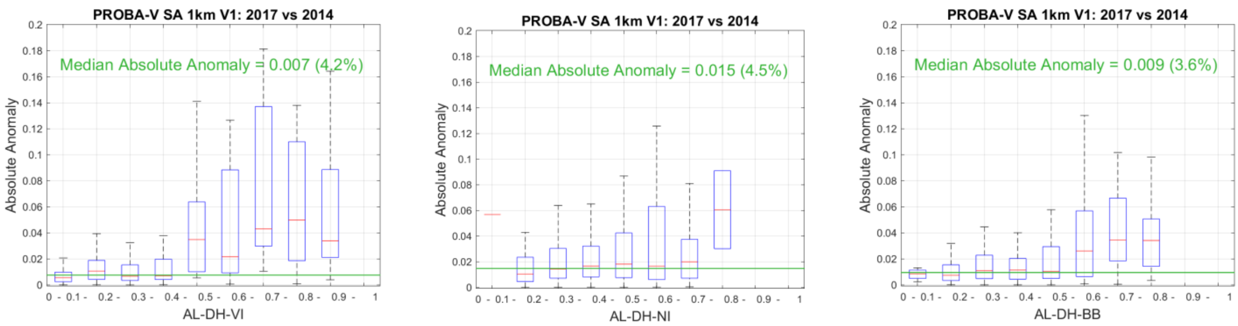


Figure 16: Box-plots of inter-annual absolute anomalies of PROBA-V SA 1km V1 (year 2017 versus year 2014) for AL-DH-VI, AL-DH-NI and AL-DH-BB. The computation was performed per bin SA value corresponding to 2017 year. Red bars indicate median values and green line corresponds to the median absolute anomaly including all SA ranges.

Median absolute anomalies (defined as indicators of the inter-annual precision) of 0.007 (4.2%), 0.015 (4.5%) and 0.009 (3.6%) were found for visible, NIR and shortwave spectral domains, which are far from fulfilling the GCOS requirements in terms of stability (Max [1%; 0.001]).

5.1.4.2 Calibration sites

The inter-annual precision between recent (2017 year) and validated (2014) PROBA-V SA V1 products was also evaluated over the desertic calibration sites. Figure 17 and Figure 18 show the PROBA-V 2017 versus PROBA-V 2014 scatter-plots and associated metrics for black-sky and white-sky albedo products. Note than the percentage of cases within the GCOS requirements in terms of stability (Max [1%; 0.001]) was computed in each case.

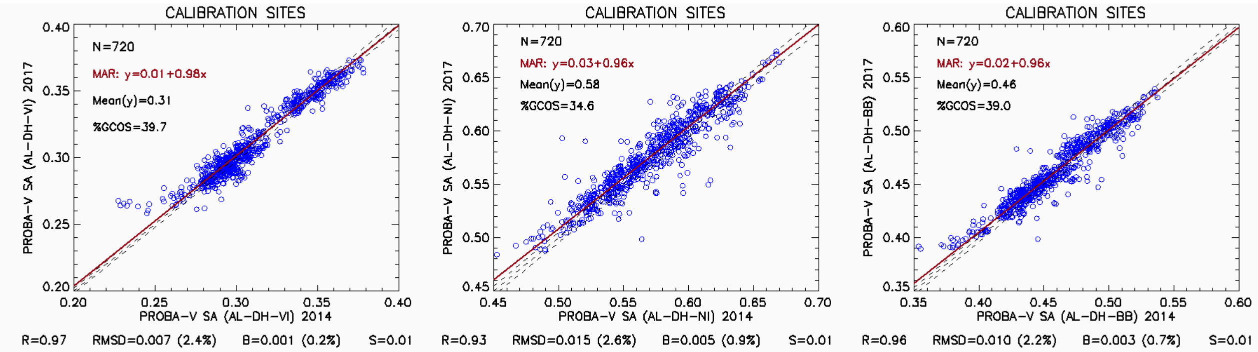


Figure 17: PROBA-V SA during 2017 year versus 2014 year scatter-plots over desertic calibrations sites for AL-DH-VI (left), AL-DH-NI (middle) and AL-DH-BB (right) spectral domains. Dashed lines correspond to the GCOS requirements in terms of stability around the 1:1 continuous line.

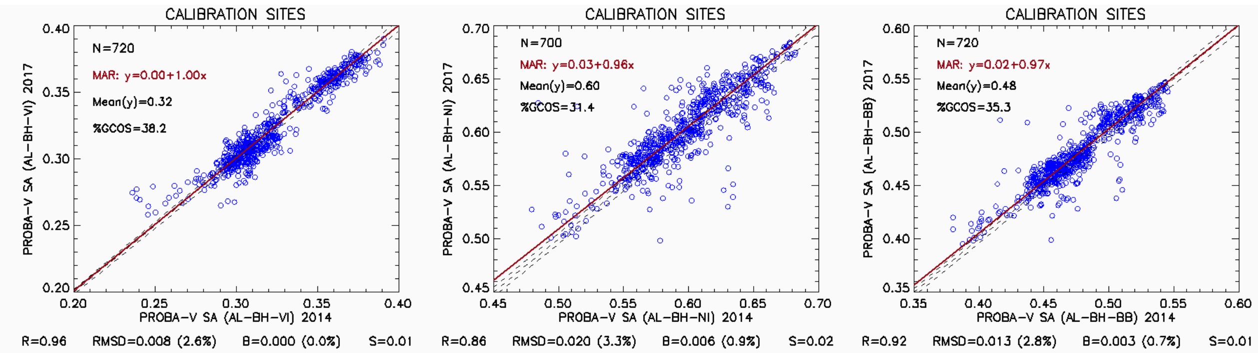


Figure 18: As in Figure 17 for AL-BH.

Main conclusions are:

- Between 30% and 40% of pixels over desertic calibration sites achieved the GCOS requirements in terms of stability (Max [1%; 0.001]).
- GCOS requirements in terms of stability are achieved in terms of mean bias, which is close to 0 for visible domain, 0.9% for NIR and 0.7% for the shortwave. GCOS requirements are not achieved in terms of RMSD with values typically around 2- 3%.

5.1.5 Intra-Annual precision (Smoothness)

Figure 19 and Figure 20 show the cumulative histograms of the smoothness (δ), for PROBA-V recent 2017 products (purple) as compared with the PROBA-V 2014 (blue) and SPOT/VGT 2012 (green) for black-sky and white-sky albedos.

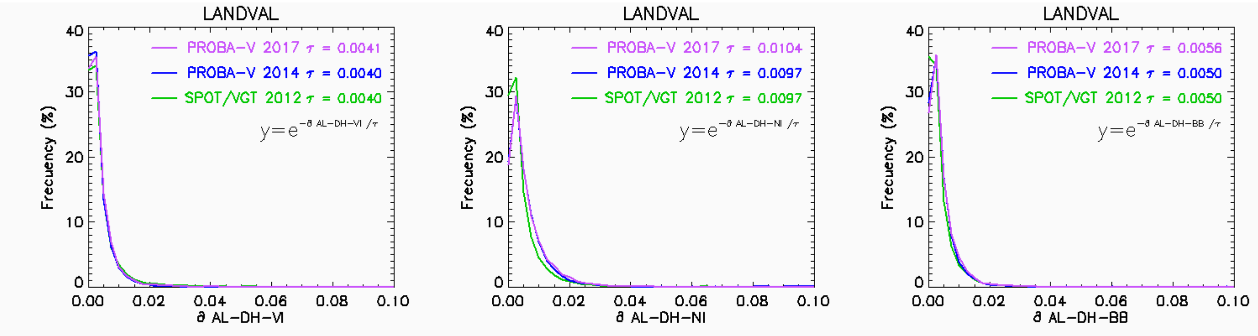


Figure 19: Histograms of the delta function (smoothness) for AL-DH-VI, AL-DH-NI and AL-DH-BB products of the PROBA-V (2017 and 2014 years, purple and blue lines) and SPOT/VGT (2012 year, green line) SA products. The curves are adjusted to an exponential function and the exponential decay constant (τ) is presented in the figure.

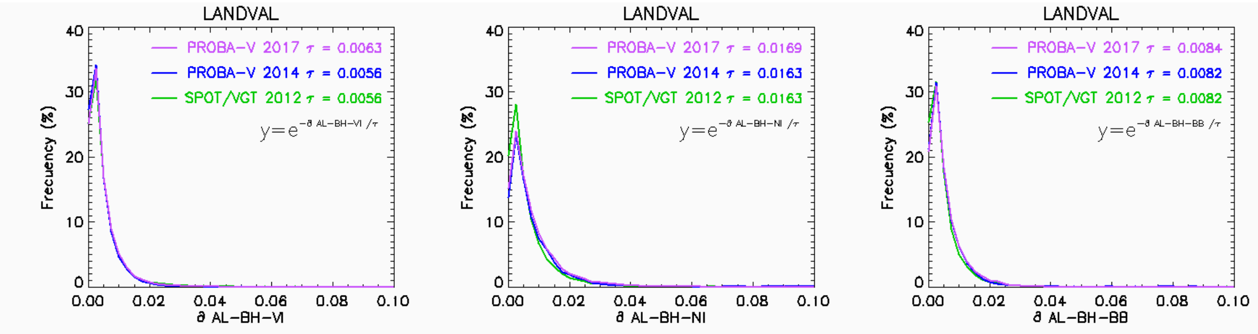


Figure 20: Histograms of the delta function (smoothness) for AL-BH-VI, AL-BH-NI and AL-BH-BB products of the PROBA-V (2017 and 2014 years, purple and blue lines) and SPOT/VGT (2012 year, green line) SA products. The curves are adjusted to an exponential function and the exponential decay constant (τ) is presented in the figure.

As shown in Figure 19 and Figure 20:

- Recent PROBA-V (2017) and validated PROBA-V (2014) and SPOT/VGT (2012) SA products present almost identical distributions of the delta function. Most of the delta values are below 0.01 which demonstrates the high stability at short time scale of the products. The cumulative histograms fit a negative exponential function, with very similar low decay constant (τ), but slightly higher in case of 2017.

- White-sky albedos showed slight degraded intra-annual precision than black-sky albedos in all spectral domains for both PROBA-V and SPOT/VGT products.

5.1.6 Overall Spatio-Temporal consistency

In this section the spatio-temporal consistency of PROBA-V SA 2017 products was evaluated against validated PROBA-V and SPOT/VGT products during the 2014 and 2012 years respectively. Note that the analysis is focused on AL-DH retrievals, and the equivalent analysis for AL-BH is presented in ANNEX I.

5.1.6.1 Global scatter-plots

The spatio-temporal consistency between recent (2017 year) and reference (2014, 2012) SA V1 products was statistically assessed over the LANDVAL network of sites. Figure 21 shows the PROBA-V 2017 versus PROBA-V 2014 scatter-plots and associated metrics for AL-DH-VI, AL-DH-NI and AL-DH-BB, and Figure 22 the PROBA-V 2017 versus SPOT/VGT 2012 scatter-plots.

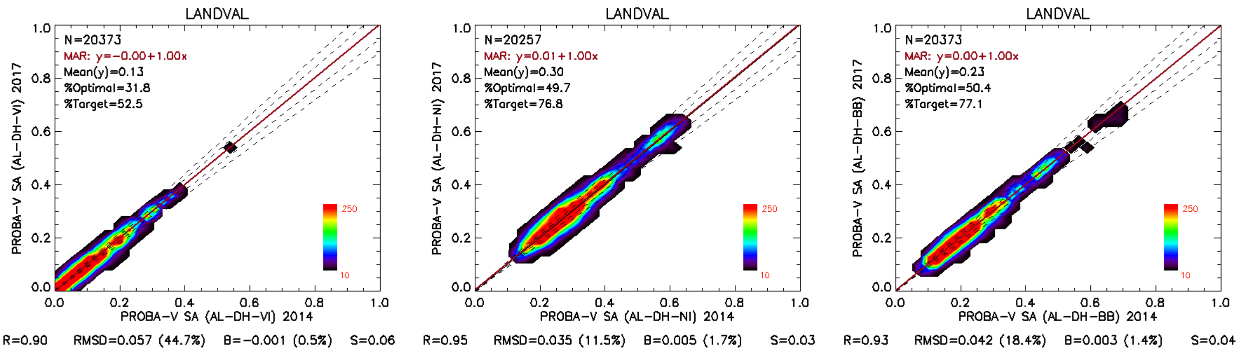


Figure 21: PROBA-V SA during 2017 year versus 2014 year scatter-plots over all LANDVAL sites for AL-DH-VI (left), AL-DH-NI (middle) and AL-DH-BB (right) spectral domains. Dashed lines correspond to the Optimal and Target uncertainty levels around the 1:1 continuous line.

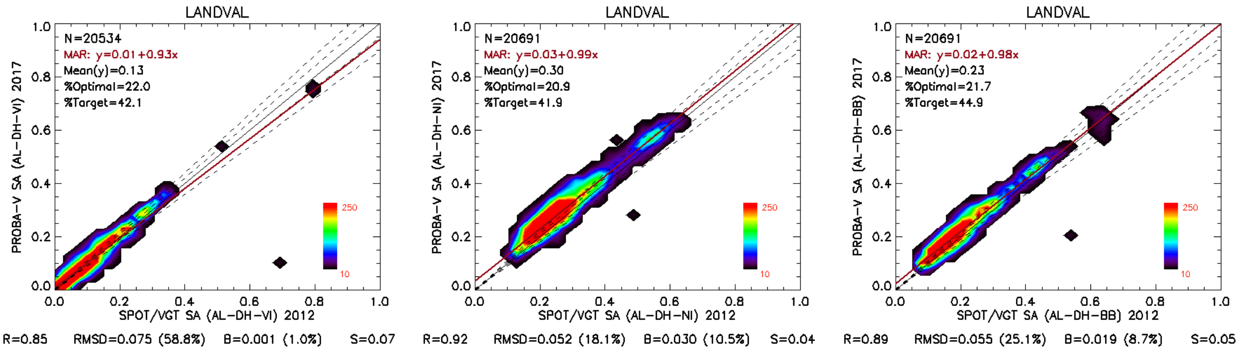


Figure 22: PROBA-V SA during 2017 year versus SPOT/VGT SA during 2012 year scatter-plots over all LANDVAL sites for AL-DH-VI (left), AL-DH-NI (middle) and AL-DH-BB (right) spectral domains. Dashed lines correspond to the Optimal and Target uncertainty levels around the 1:1 continuous line.

The comparison of PROBA-V 2017 versus PROBA-V 2014 (Figure 21) shows:

- For AL-DH-VI, good correlations were found (R=0.9), with RMSD of 0.057 and almost no mean bias (-0.5%). 31.8% of pixels showed optimal (GCOS) consistency, with more than 52% of samples fulfilling the target level.
- Good results were also found for AL-DH-NI in terms of correlation (R=95), showing RMSD of 0.035 and slight positive bias of 1.7%. Around the half of samples showed optimal consistency (~77% within the target level).
- For AL-DH-BB, high correlation of 0.93 was found, with low RMSD of 0.042 and slight positive bias of 1.4%. More than the half of pixels is within the optimal level of consistency (~77% within the target level).
- In summary, good spatio-temporal consistency was found between recent (2017) and validated (2014) PROBA-V SA products. Noteworthy optimal lineal regression was found (offset ~0 and slope ~1) in all spectral channels.
- Regarding white-sky products (ANNEX I), very similar results were found compared with black-sky similar products, showing slight degraded statistics.

On the other hand, main results from the comparison of PROBA-V 2017 versus SPOT/VGT 2012 (Figure 22) are:

- For AL-DH-VI, overall statistics of R=0.85, RMSD=0.075 and low bias of 1% were found. 22% of pixels showed optimal (GCOS) consistency, with more than 42% of samples fulfilling the target level.
- Regarding AL-DH-NI, overall statistics showed high correlation of R=92, RMSD of 0.052 and positive bias of 10.5%. Around 21% showed optimal consistency (~42% within the target level).
- Similar results were found for AL-DH-BB, with high correlation of 0.89, RMSD of 0.055 and positive bias of 8.7%. Around 22% of pixels are within the optimal level of consistency (~45% within the target level).
- In summary, good spatio-temporal consistency was found between recent (2017) and reference SPOT/VGT (2012) SA products. Positive bias was found for AL-DH-NI and AL-DH-BB, mainly observed for the lowest albedo ranges (offset ~0.2-0.3 and slope <1), which confirms the conclusions of the validation report (CGLOPS1_VR_SA1km-PROBAV-V1.5), where positive bias of around 5% was found between PROBA-V and SPOT/VGT SA V1 products during the overlap period of both sensors.
- Very similar results were found for white-sky products (ANNEX I).

5.1.6.2 Box-plot of uncertainties per bin

The analysis of the discrepancies (bias and RMSD) between recent PROBA-V SA V1 (2017) products was analyzed per range albedo value as compared to references PROBA-V 2014 (Figure 21) and SPOT/VGT 2012 (Figure 22) years. The computation was performed over LANDVAL network of sites.

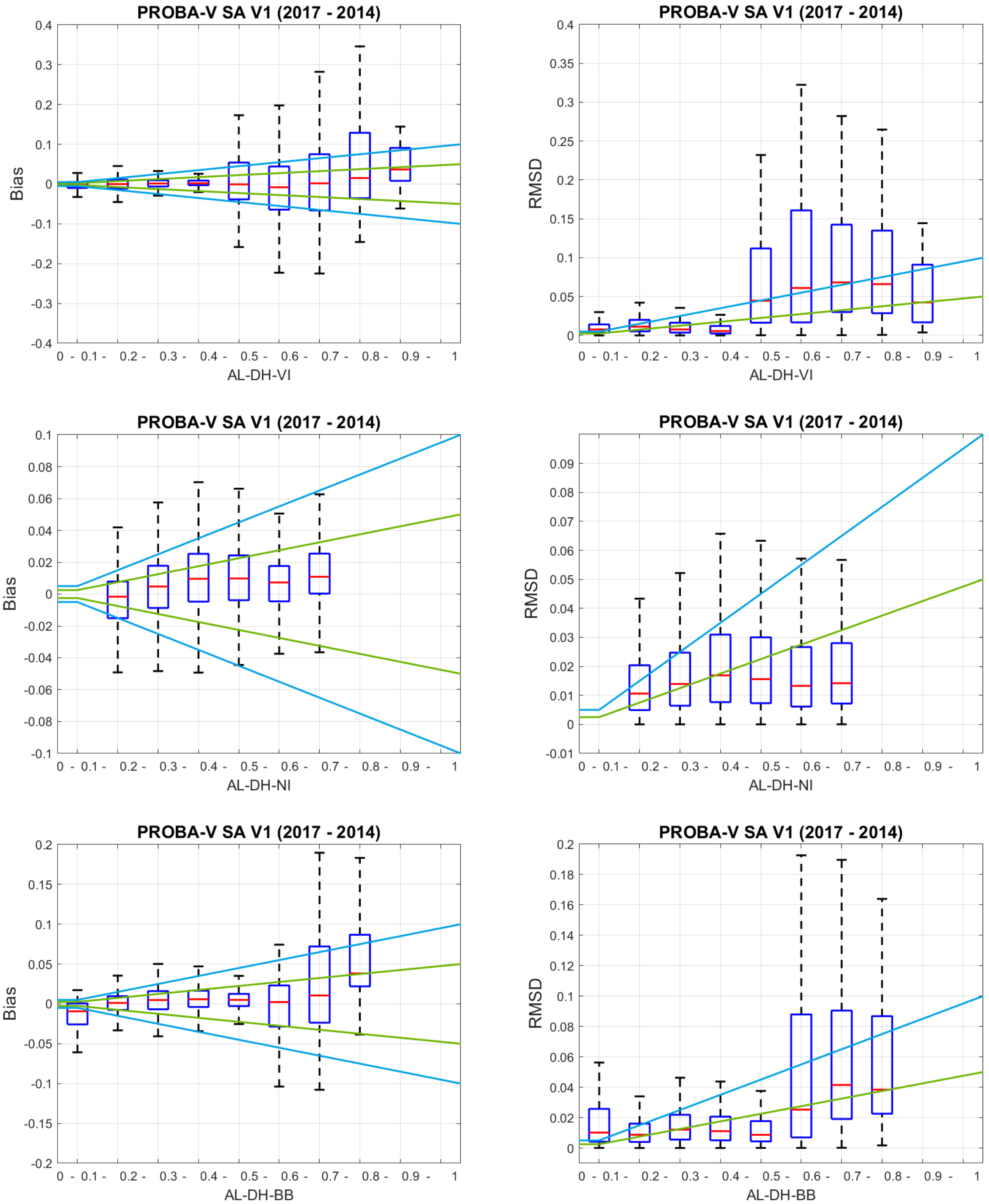


Figure 23: Box-plots of uncertainty statistics between PROBA-V SA recent (2017) and validated (2014) years (Bias: left side, RMSD: right side) per bin (2017 year) for AL-DH-VI (Top), AL-DH-NI (Middle) and AL-BH-BB (Bottom). Red bars indicate median values, blue boxes stretch from the 25th percentile to the 75th percentile of the data and whiskers include 99.3% of the coverage data (±2.7 σ). Outliers are not displayed. Green and Blue lines correspond to optimal and target uncertainty levels.

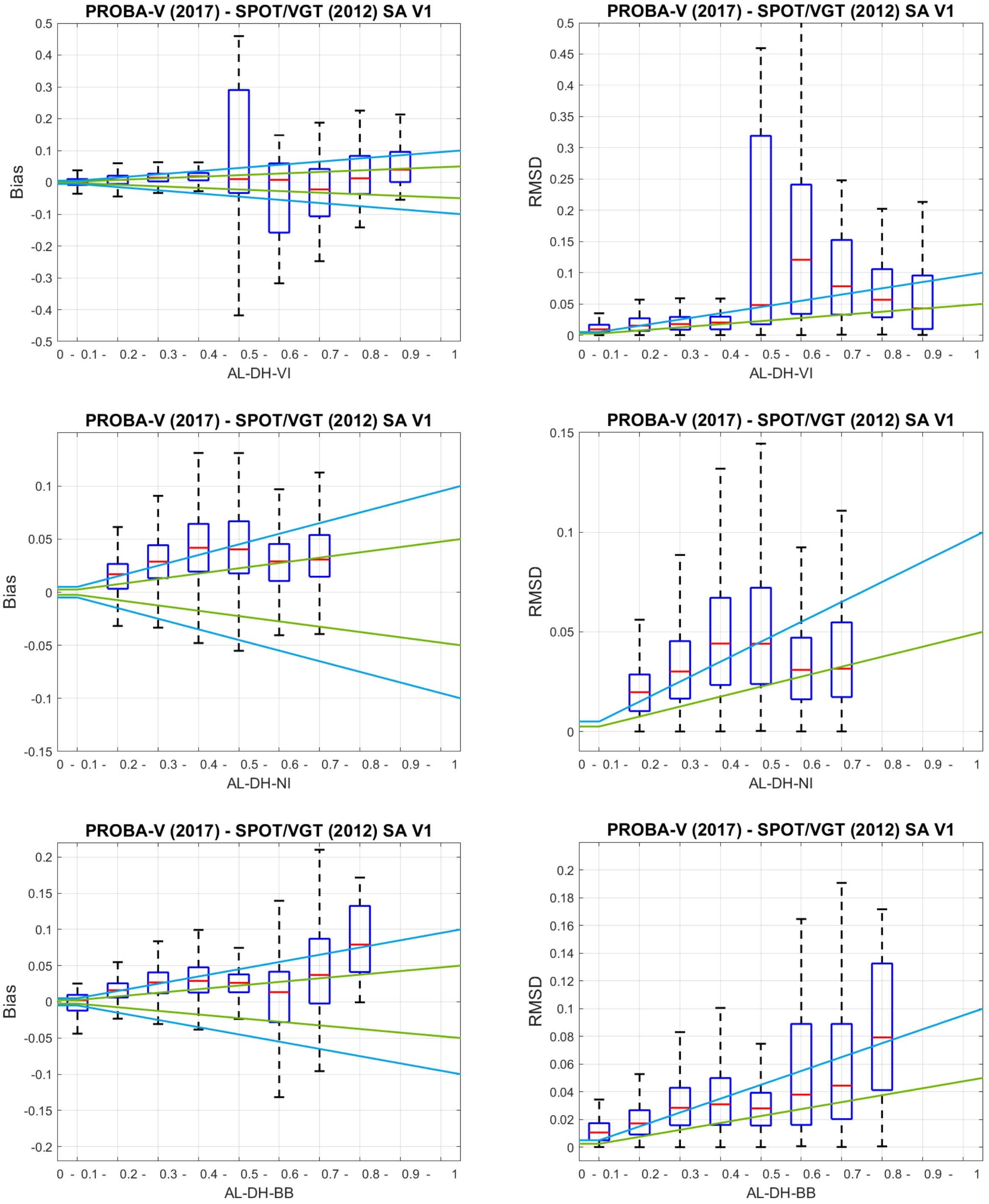


Figure 24: Box-plots of uncertainty statistics between PROBA-V SA recent 2017 and reference SPOT/VGT 2012 years (Bias: left side, RMSD: right side) per bin (2017 year) for AL-DH-VI (Top), AL-DH-NI (Middle) and AL-BH-BB (Bottom). Red bars indicate median values, blue boxes stretch from the 25th percentile to the 75th percentile of the data and whiskers include 99.3% of the coverage data (±2.7 σ). Outliers are not displayed. Green and Blue lines correspond to optimal and target uncertainty levels.

The conclusions of the comparison between PROBA-V 2017 versus PROBA-V 2014 (Figure 23) are:

- For AL-DH-VI, median absolute bias is lower than the limit of the optimal consistency (see green lines) for all albedo ranges, large scattering for albedo values higher than 0.5 (typically snow). In terms of RMSD, median values are around the optimal limit for albedo values ranges of 0.2-0.4 and 0.8-0.9, and around the target limit for the rest of ranges.
- For AL-DH-NI, optimal consistency between 2017 and 2014 was found for all albedo ranges, showing median bias fulfilling the optimal level of consistency and typically more than 50% of samples within the target level. Similar performance was found in terms of RMSD.
- In case of AL-DH-BB, optimal mean bias (close to zero) was found for albedo values between 0.1 and 0.7. For the lowest range (0-0.1) negative bias was found whereas the opposite trend was found for the highest valid range (0.7-0.8). Median RMSD values fulfilled the optimal consistency for most of the ranges with the exception of 0-0.1 (out of target level) and 0.6-0.7 (target level). Albedo ranges higher than 0.5, typically affected by snow, showed large scattering of RMDS values.
- Similar conclusions of black-sky albedos should be applied to black-sky albedos, as showed in ANNEX I.

In case of the comparison between PROBA-V 2017 versus SPOT/VGT 2012 (Figure 24):

- For the visible domain, box-plots show median bias within the optimal (GCOS) level, showing slight systematic trend towards positive differences. Median RMSD values are within the target level of consistency for all albedo ranges except for values between 0.5 and 0.7. Large scattering was found for 0.4-0.6 range, affected by the presence of snow pixels.
- For AL-DH-NI, PROBA-V (2017 year) tends to provide higher values than SPOT/VGT (2012 year) for all albedo ranges, in line to that found during the validation report (see CGLOPS1_VR_SA1km-PROBAV-V1.5). Median RMSD within the target level was found for albedo values higher than 0.4, whereas median RMSD out of the target level was found for the lowest ranges (<0.4).
- For the shortwave domain, systematic positive bias was found for all ranges, with median values typically between the optimal (GCOS) and target level of consistency. Similar results were found in terms of RMSD.
- Similar trend was found for black-sky and white-sky albedos (see ANNEX I).

5.1.6.3 Distribution of retrievals and residuals per Biome Type

The distribution of values and retrievals was computed over LANDVAL for SA V1 products during the recent period under study (PROBA-V, 2017 year) and the reference periods of PROBA-V (2014 year) and SPOT/VGT (2012 year), and presented per biome type in Figure 25 and Figure 26 respectively.

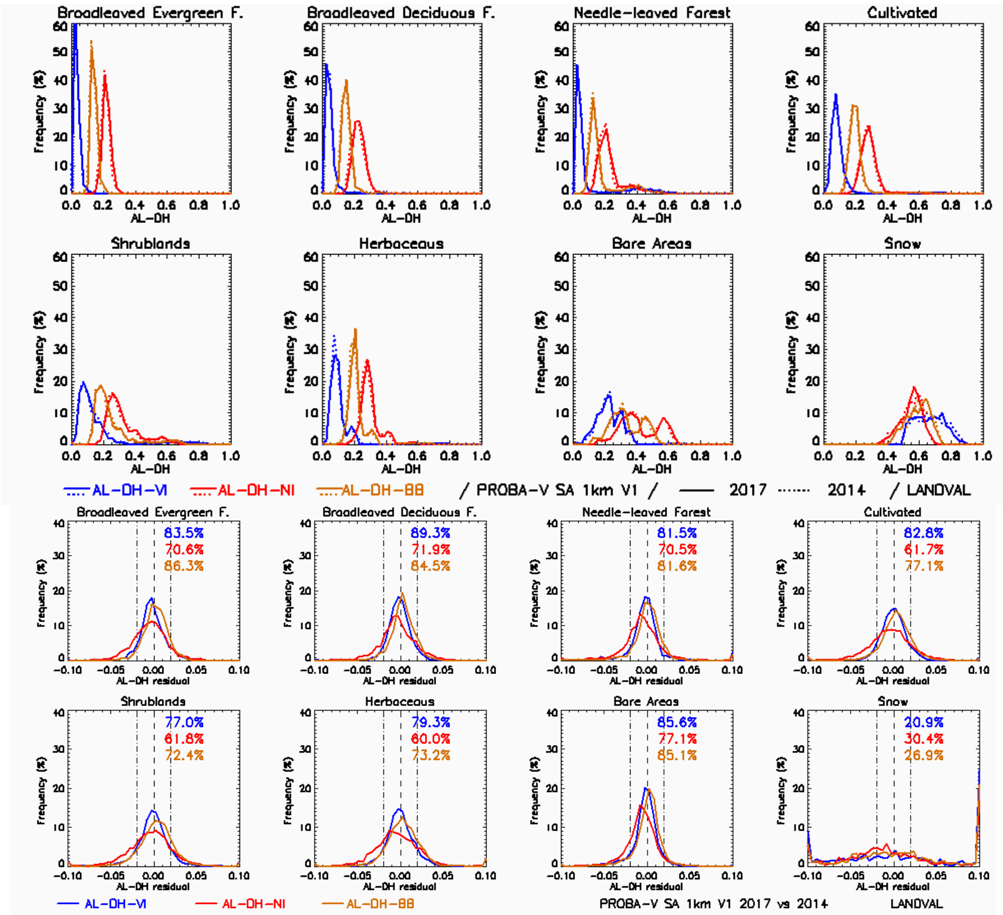


Figure 25: Top: distribution of PROBA-V SA (DH) values for 2017 (continuous lines) and 2014 (dashed lines). Bottom: Residuals between PROBA-V SA 2017 versus 2014 years. Computation over LANDVAL sites during one year of data (January-December) for each main biome type.

The comparison of PROBA-V 2017 versus PROBA-V 2014 per biome type (Figure 25):

- Almost identical distribution of retrievals was found for PROBA-V SA recent (2017) and validated (2014) products for all biome type and spectral band. Only some differences were found over snow pixels.
- AL-DH residuals between ±0.02 were found in typically more than 60% of cases for all biome type. The exception is the snow, where lower percentages were found (~20% – 30%).
- Similar trend was found for white-sky albedos (ANNEX I), showing similar distribution of retrievals, and typically more 50% of cases showing AL-BH residuals between ±0.02 for all biomes except for snow.

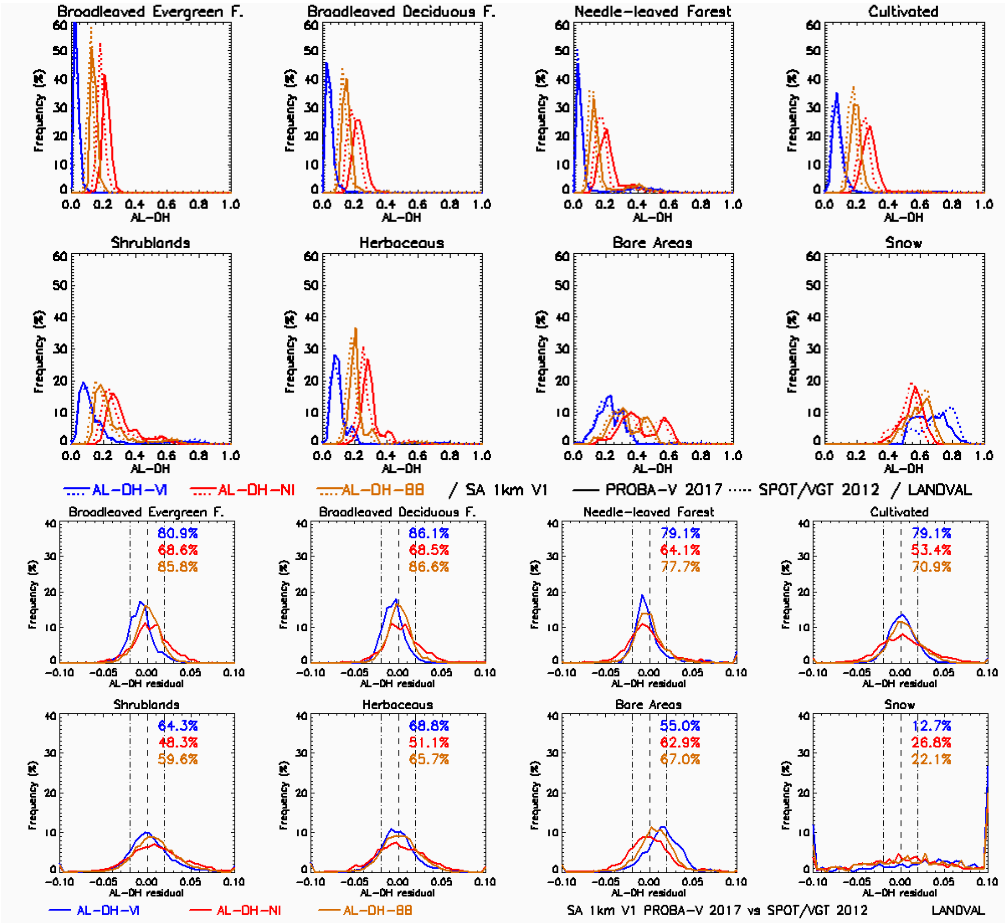


Figure 26: Top: distribution of PROBA-V SA (DH) values for 2017 (continuous lines) and SPOT/VGT 2012 (dashed lines). Bottom: Residuals between PROBA-V SA 2017 versus SPOT/VGT 2012 years. Computation over LANDVAL sites during one year of data (January-December) for each main biome type.

The comparison per biome type between recent PROBA-V 2017 and reference SPOT/VGT 2012 (Figure 26) SA V1 products showed:

- Similar distribution of retrievals was found for PROBA-V recent (2017) and reference SPOT/VGT (2012) products for AL-DH-VI. For AL-DH-NI and AL-BH-BB, a clear tendency towards large retrievals was found in case of PROBA-V for all biome types, except for snow.
- Regarding the distribution of residuals, AL-DH residuals are between ±0.02 in typically more than 50% of cases except in snow.
- Similar trend was found for white-sky albedos (ANNEX I), with lower percentage of cases where residuals are ±0.02.

5.2 REGIONAL ANALYSIS

5.2.1 Spatial Consistency

5.2.1.1 Visual inspection of regional maps

Maps of PROBA-V SA V1 products have been analyzed over the sub-continental region (West Africa) of interest during the period under study (2017 year), and visually compared with equivalent dates during the validated period (2014 year). These maps were displayed at the full resolution of the PROBA-V Collection 1km products (i.e. 1/112º). Figure 27 shows some examples for the black-sky albedo around mid of April, and ANNEX II displays the sub-continental maps during the whole 2017 year (one example per month) for both black-sky and white-sky albedos in all spectral ranges.

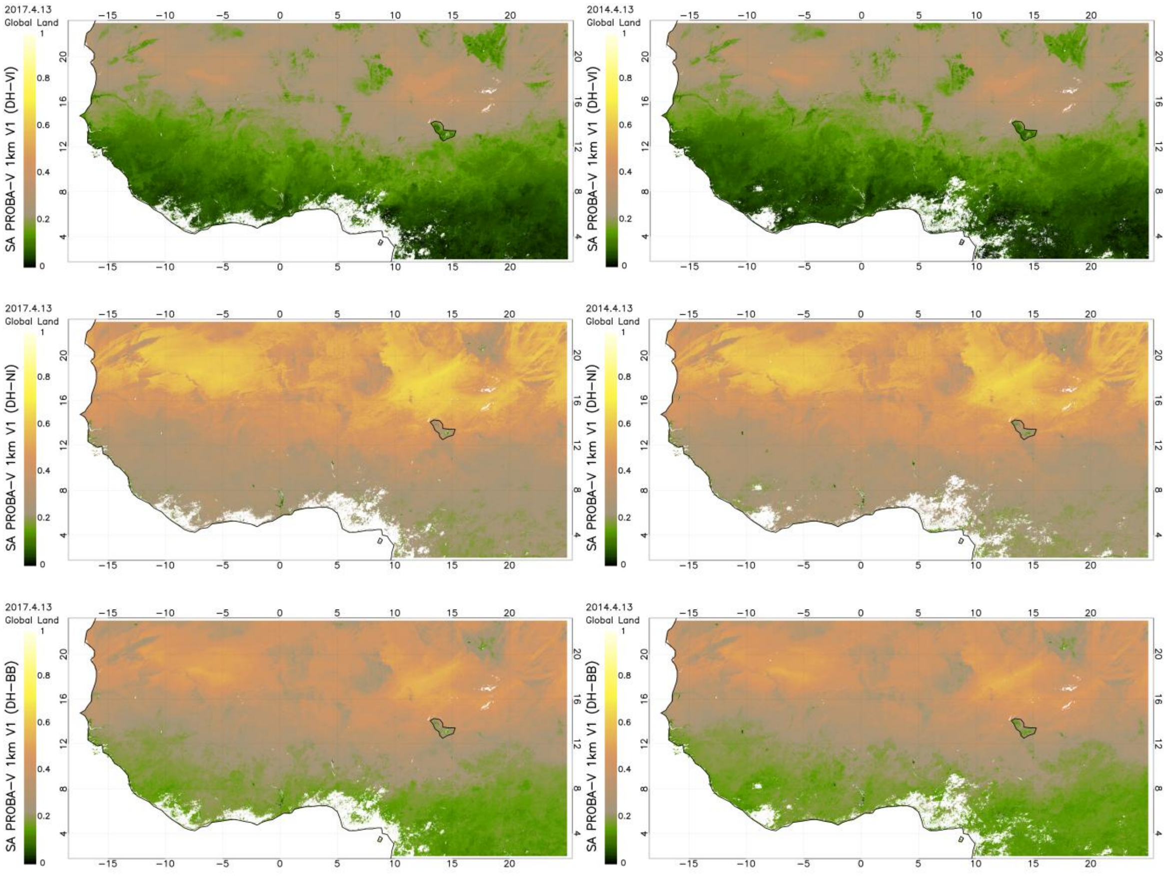


Figure 27: Maps of PROBA-V SA V1 products for the sub-continental region (West Africa) for 13th April 2017 (left) and 2014 (right). From Top to Bottom: AL-DH-VI, AL-DH-NI and AL-DH-BB.

As showed in Figure 27 and ANNEX II, the inspection of the maps over West-African region showed consistent distribution of values without finding any artifacts or suspicious patterns for all the dates and albedo layers.

5.2.2 Temporal Consistency

5.2.2.1 Temporal variations per biome type over West Africa

In this section, the temporal variations of PROBA-V SA 1km V1 recent (2017) and validated (2014) products were analyzed over West Africa region per biome type. For this purpose, temporal profiles of surface albedo averaged values (AL-DH-VI, AL-DH-NI and AL-DH-BB) of each main biome type are displayed from Figure 28 to Figure 30.

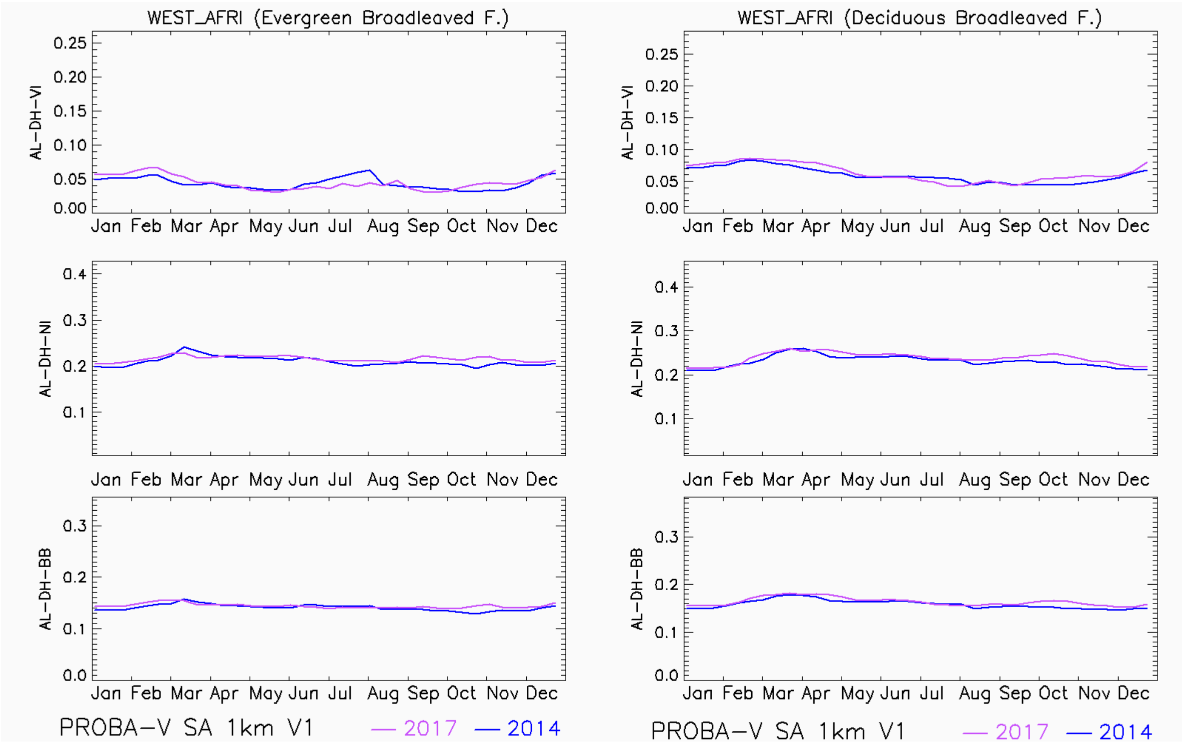


Figure 28: Temporal profiles of PROBA-V SA 1km V1 product (black-sky albedos) during 2017 (purple line) and 2014 (blue line) years. The computation was performed by averaged values of EBF (left side) and DBF (right side) pixels over the West Africa region.

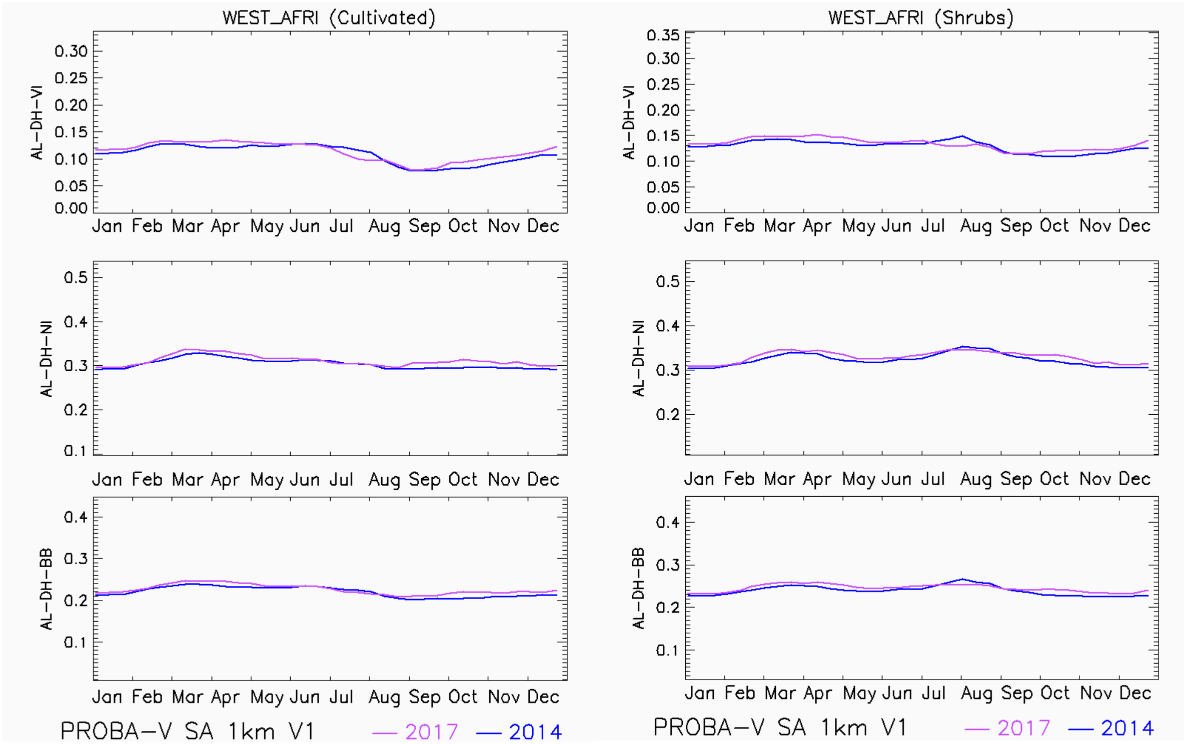


Figure 29: As in Figure 28 for Cultivated (left side) and Shrubs (right side) pixels over the West Africa region.

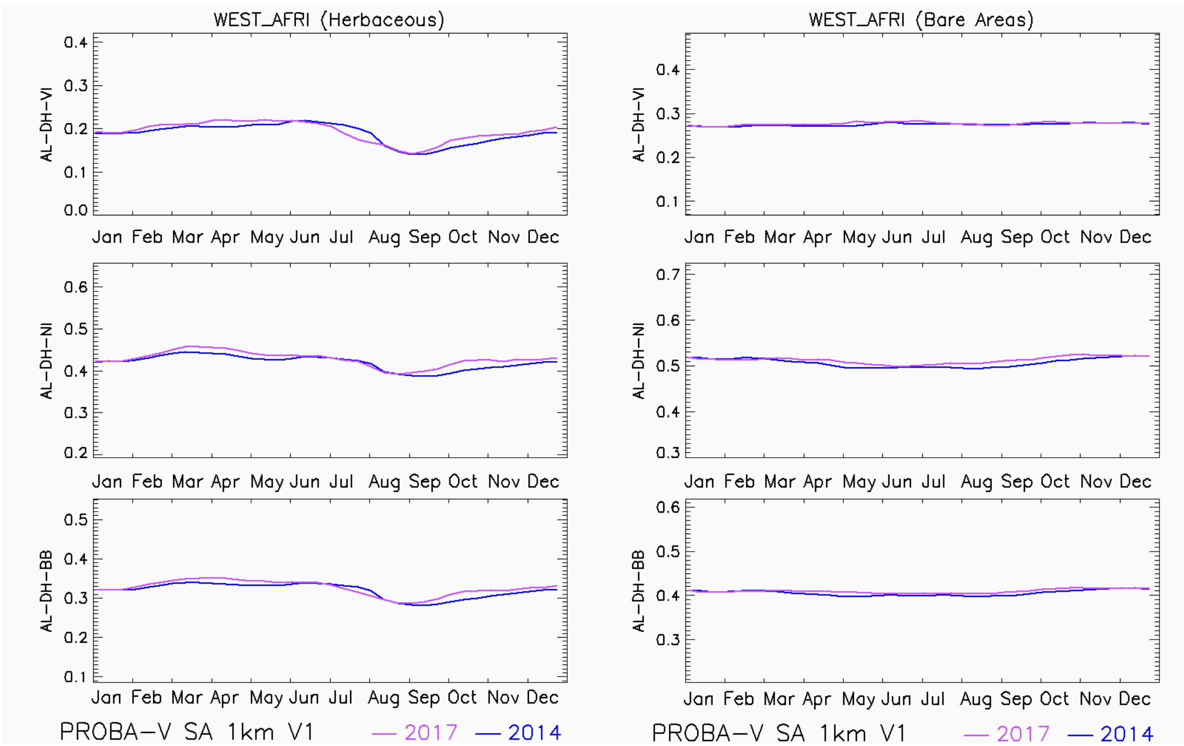


Figure 30: As in Figure 28 for Herbaceous (left side) and Bare Areas (right side) pixels over the West Africa region.

Similar temporal trajectories were found during the 2017 and 2014 years for PROBA-V SA 1km V1 product in all spectral channels for all biome type over the West Africa region, which demonstrate that the temporal consistency of the product is preserved. Note that these figures were showed for back-sky albedos, but almost identical temporal trends were found for white-sky albedos.

5.2.2.2 Temporal Variations over Specific Fire Events

The realism of the temporal profiles over specific fire events (see section 4.1.2.2, Table 11) was evaluated showing the temporal evolution of the PROBA-V SA V1 and MODIS MCD43A3 C6 surface albedo products. Temporal profiles of black-sky retrievals during the period from January 2014 to December 2017 are showed from Figure 31 to Figure 35.

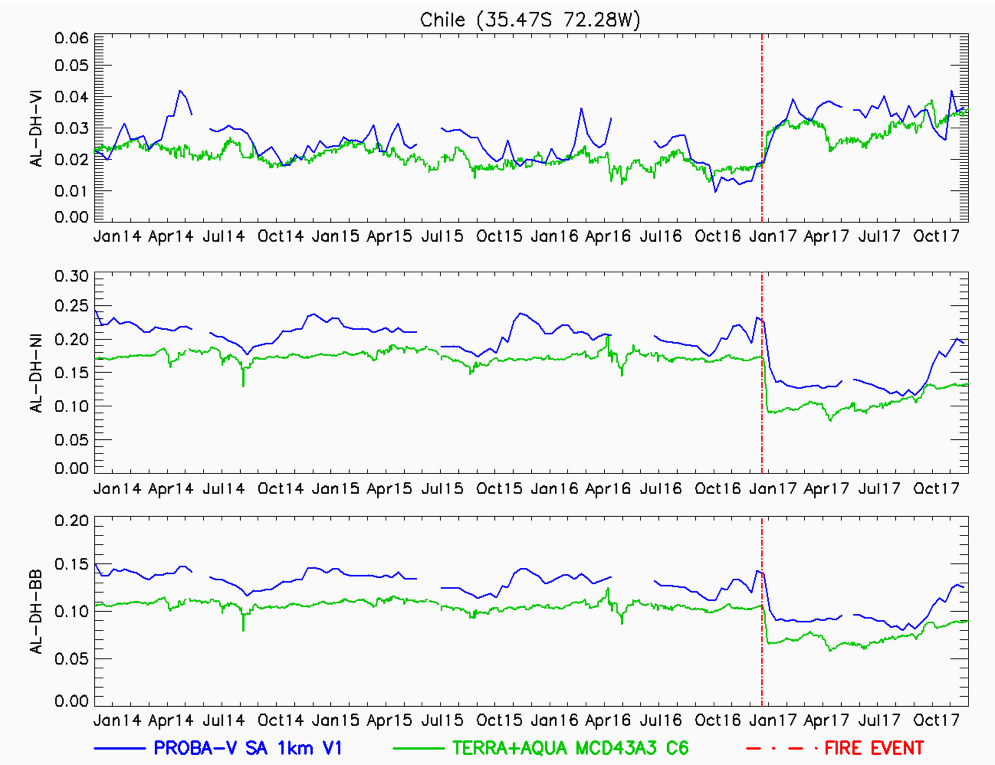


Figure 31: Temporal profiles of PROBA-V SA 1km V1 (blue line) and MCD43A4 C6 products (green line) products for black-sky albedos (AL-DH-VI, AL-DH-NI) over 'Chile' site showing and specific fire event, during the period from Januarys 2014 to December 2017. Red dash-line indicates the fire event date.

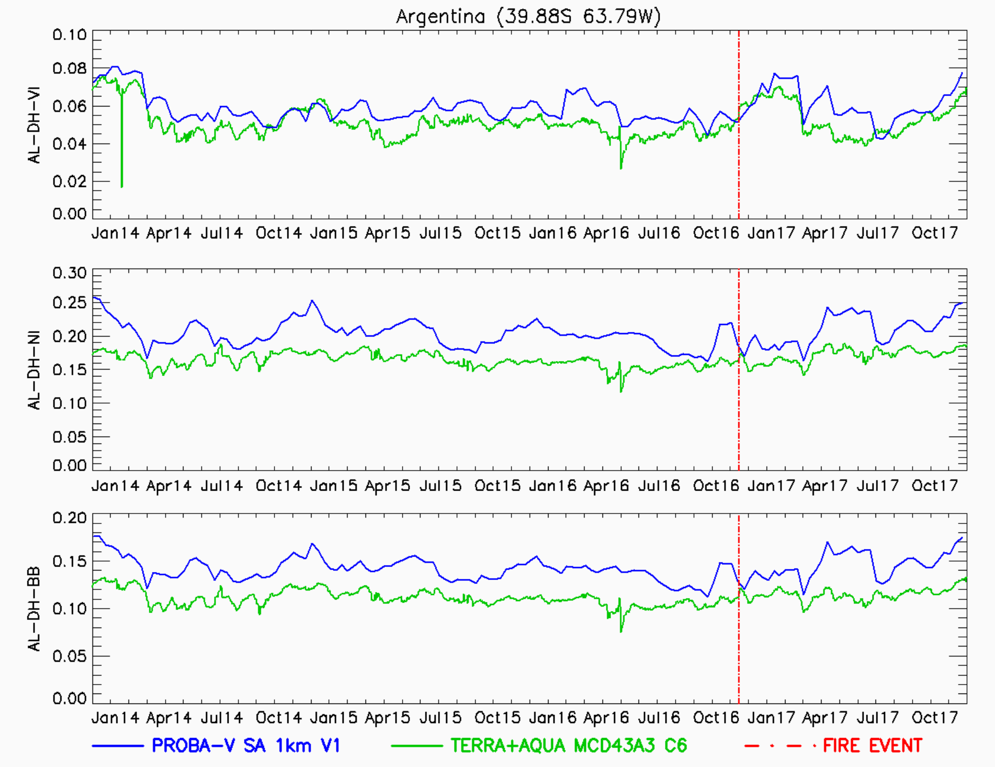


Figure 32: As in Figure 31 for 'Argentina' site.

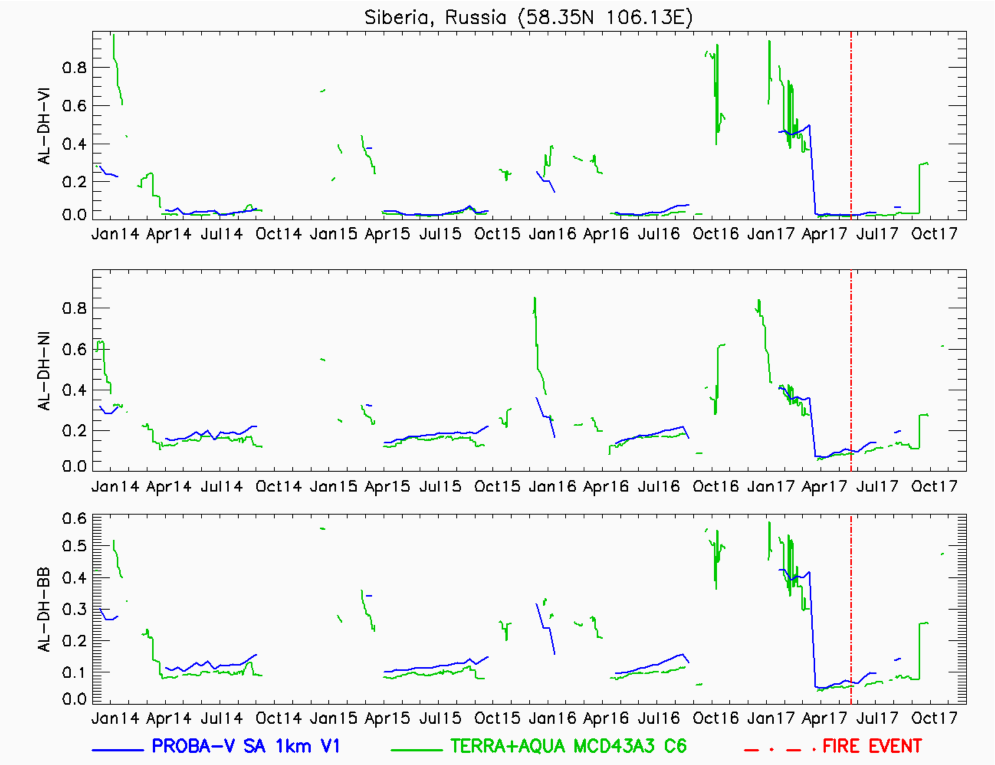


Figure 33: As in Figure 31 for 'Siberia' site.

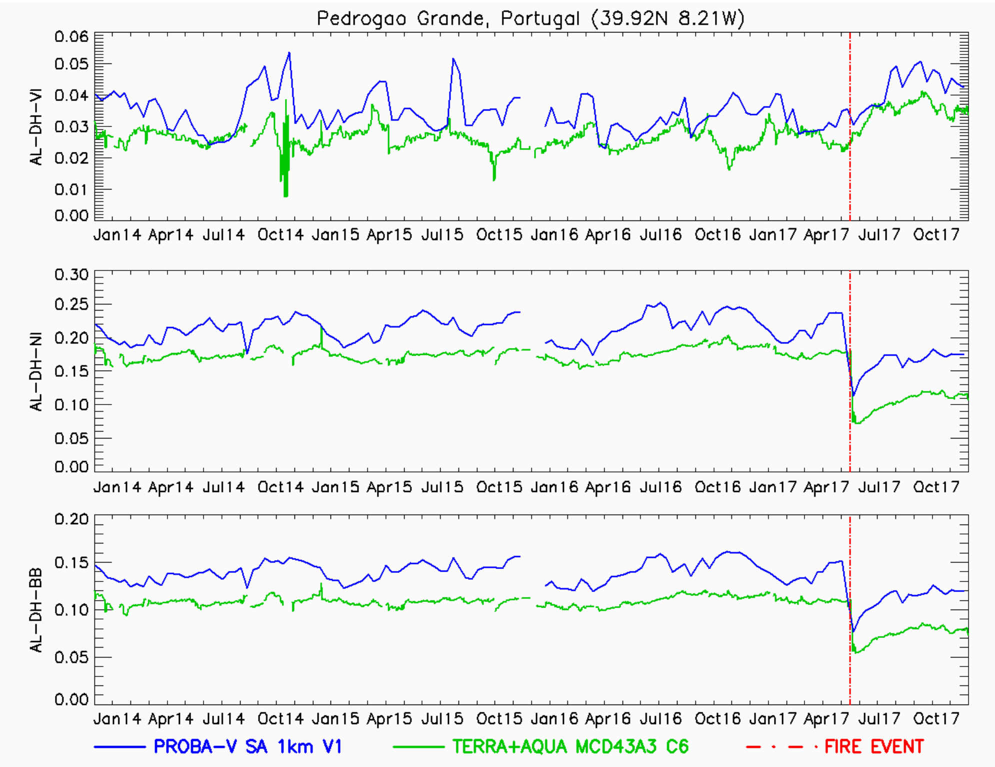


Figure 34: As in Figure 31 for 'Pedrogao Grande, Portugal' site.

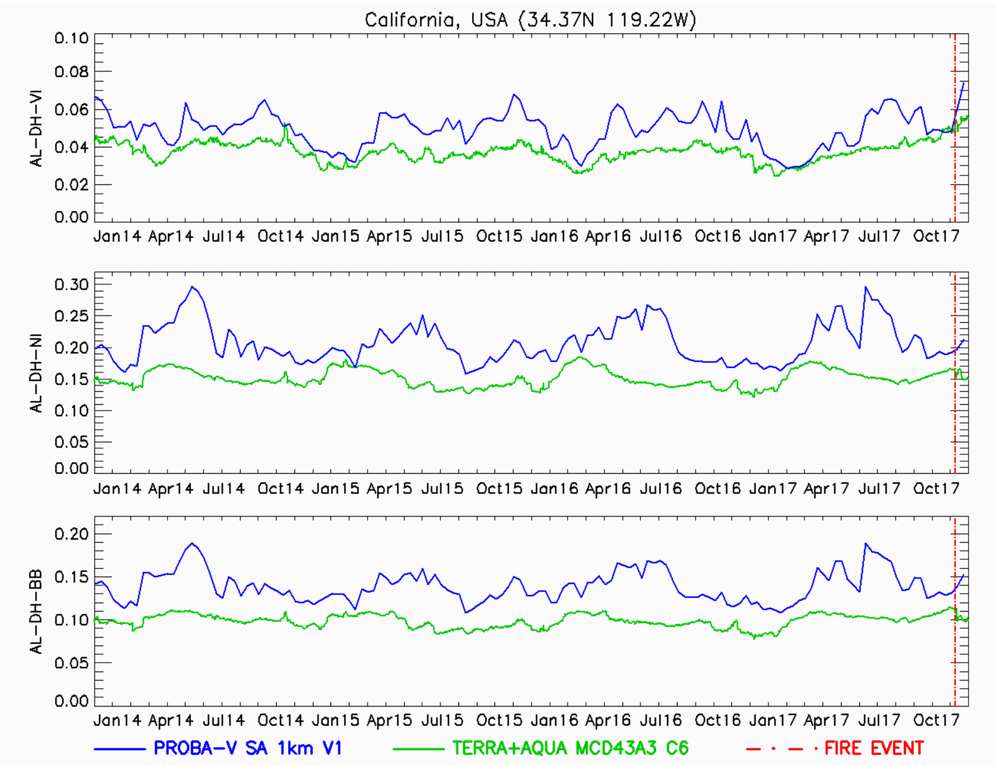


Figure 35: As in Figure 31 for 'California, USA' site.

Main findings are:

- For *Chile* (Figure 31) and *Pedrógão* (Figure 34), the fire events were well captured by PROBA-V, showing a significant decrease of the AL-DH-NI and AL-DH-BB values since the event date and the opposite trend for the AL-DH-VI. Values were found also consistent to MODIS C6.
- For *Argentina* (Figure 32), PROBA-V and MODIS C6 provides similar temporal trend. No main changes in the albedo values are observed for AL-DH-NI and AL-DH-BB since the fire event date. For AL-DH-VI, a slight increase of the albedo values is observed since the event date.
- For *Siberia* (Figure 33), similar temporal trajectories were found in both satellite products. In both cases, no main changes in the surface albedo values were observed since the fire event.
- Finally, for California (Figure 35), the PROBA-V and MODIS C6 products reproduce well the specific event in AL-DH-VI, showing an increase of the values since the fire event date. However, for AL-DH-NI and AL-DH-BB, PROBA-V shows the opposite trend to MODIS C6 (PROBA-V increases the albedo values whereas MODIS decreases).

5.2.2.3 Temporal Realism against ground measurements

Finally, the realism of the temporal profiles over sites with available ground data (see section 4.3, Table 12) was evaluated displaying the temporal evolution of blue-sky albedos computed from PROBA-V SA V1 and MODIS MCD43A3 C6 satellite retrievals during the 2017 year. Blue-sky albedos were computed by linear combination of black-sky and white-sky satellite retrievals using the diffuse fraction coming from the ground data.

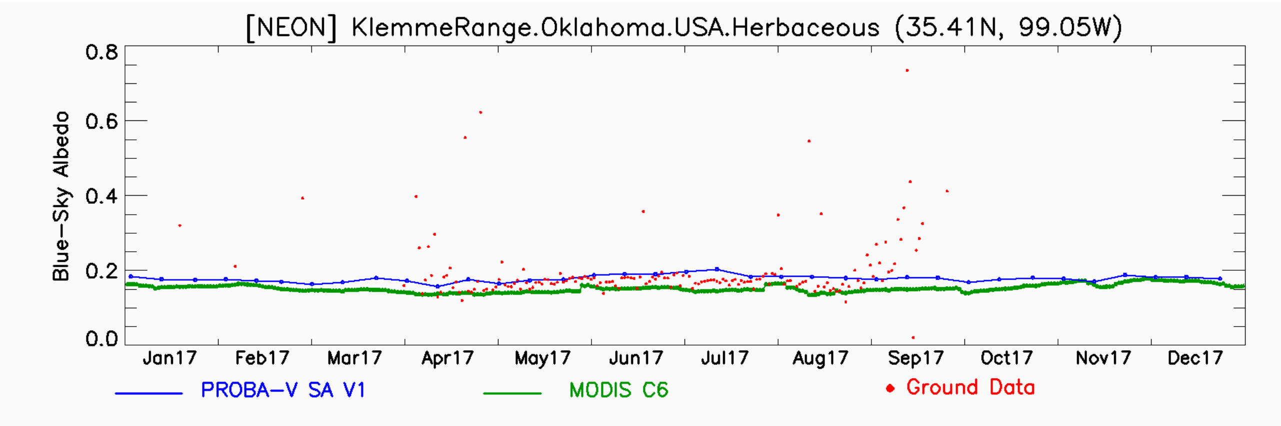


Figure 36: Temporal profiles (2017 year) of PROBA-V SA 1km V1 (blue line) and MCD43A4 C6 products (green line) blue-sky albedos and ground values (red points) coming from the NEON 'Klemme Range' station.

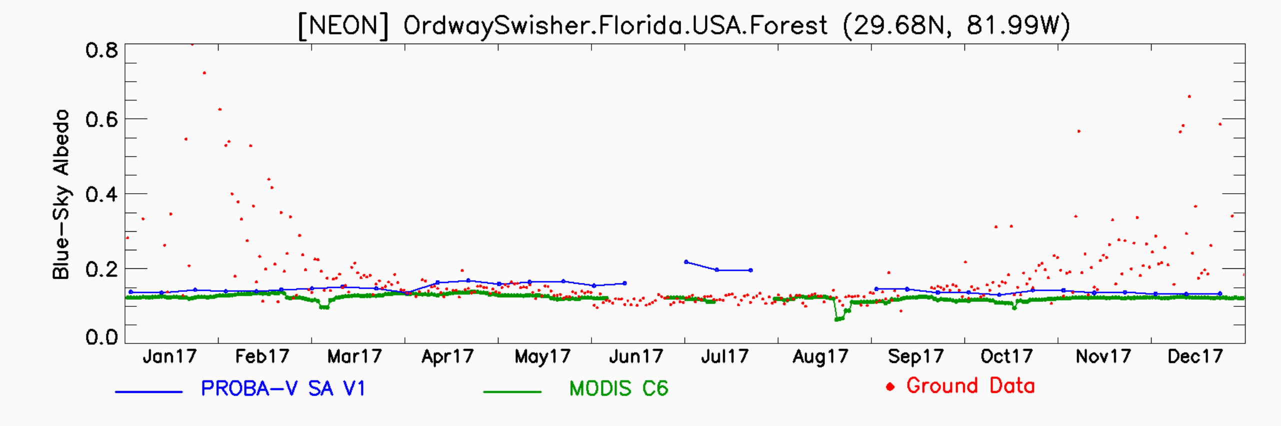


Figure 37: As in Figure 36 for NEON 'Ordway Swisher' station.

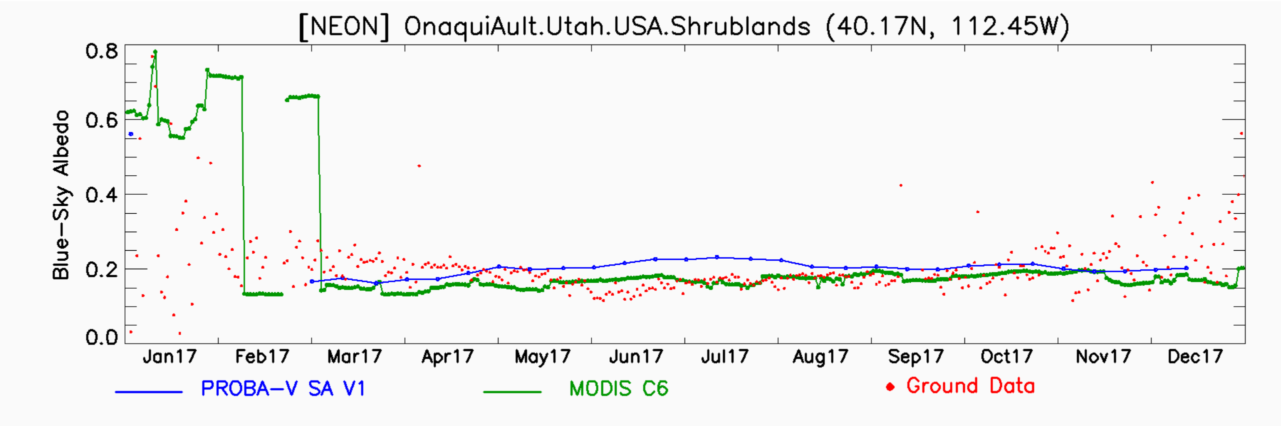


Figure 38: As in Figure 36 for NEON 'Onaqui Ault' station.

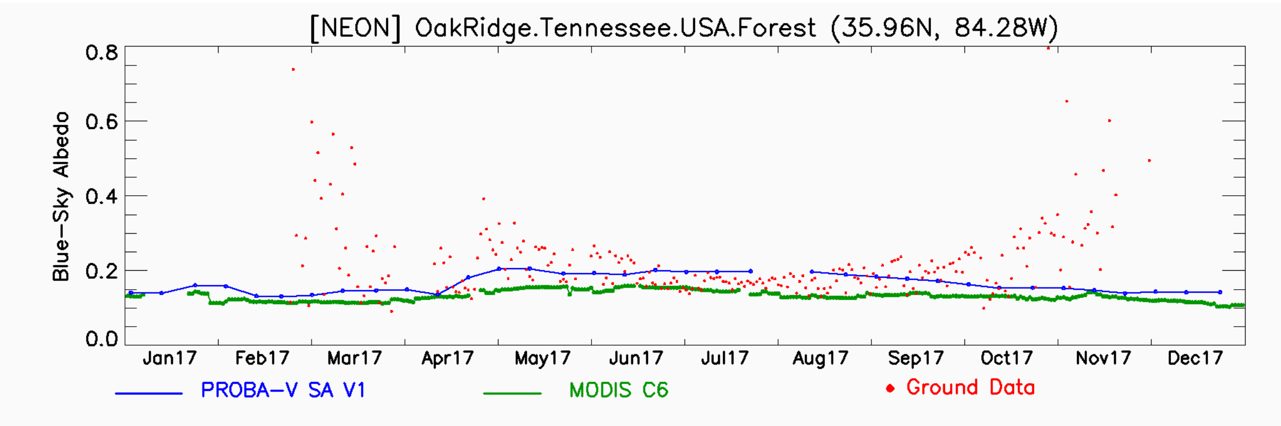


Figure 39: As in Figure 36 for NEON 'Oak Ridge' station.

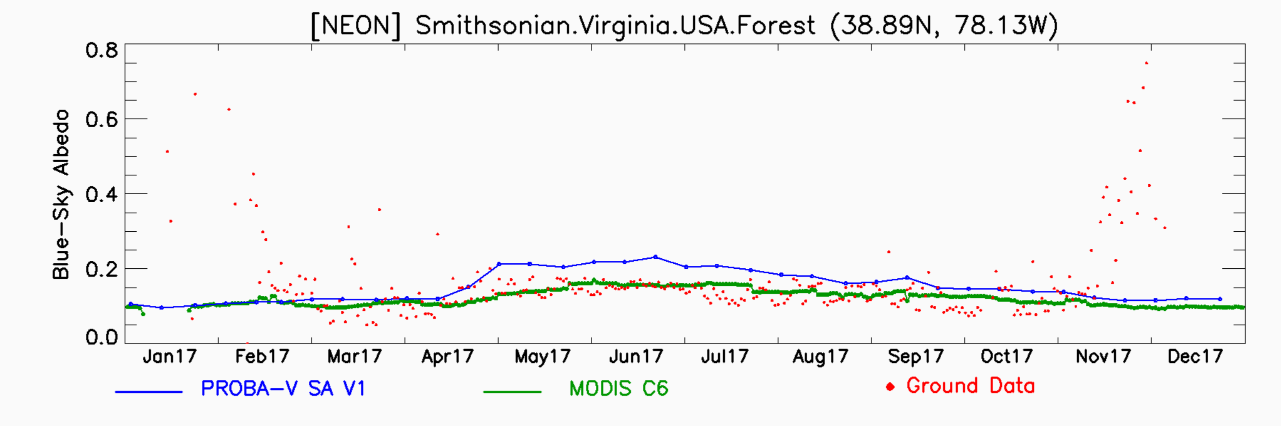


Figure 40: As in Figure 36 for NEON 'Smithsonian' station.

Main findings from Figure 36 to Figure 40 are:

- PROBA-V tends to provide similar temporal trend than MODIS C6 satellite product and ground references, but showing systematic higher albedo values.
- Snow events in 'Onaqui Ault' (Figure 38) are well captured in MODIS C6 product during the period form early January till end of February, since PROBA-V product only provides one snow observation during this period. The snow events in 'Ordway Swisher' (Figure 37), 'Oak Ridge' (Figure 39) and 'Smithsonian' (Figure 40) are not properly captured in both satellite products.

5.2.3 Statistical Consistency

5.2.3.1 Box-plots of uncertainty per biome type over West Africa

This section presents the statistical analysis of the bias and RMSD between PROBA-V 1 km V1 recent 2017 and the validated 2014 year per land cover type over the West Africa region for AL-DH-VI, AL-DH-NI and AL-DH-BB, as showed from Figure 41 to Figure 43. Note that almost identical results were found for white-sky albedos.

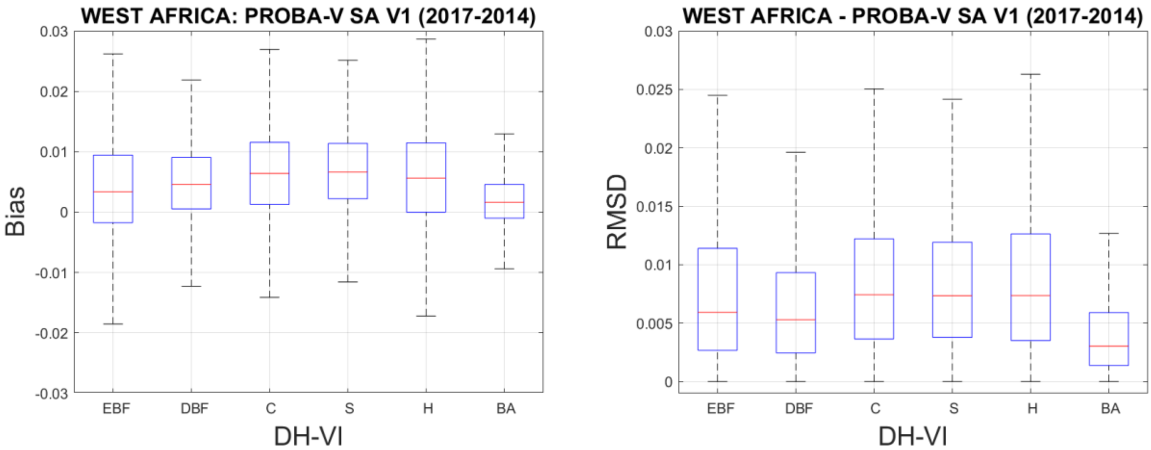


Figure 41: Box-plots of uncertainty statistics between PROBA-V SA 1km V1 recent (2017) and validated (2014) (Bias: top, RMSD: bottom) per main biome (West Africa region) for AL-DH-VI. Red bars indicate median residuals, blue boxes stretch from the 25th percentile to the 75th percentile the data and whiskers include 99.3% of the coverage data (±2.7σ). Outliers are not displayed.

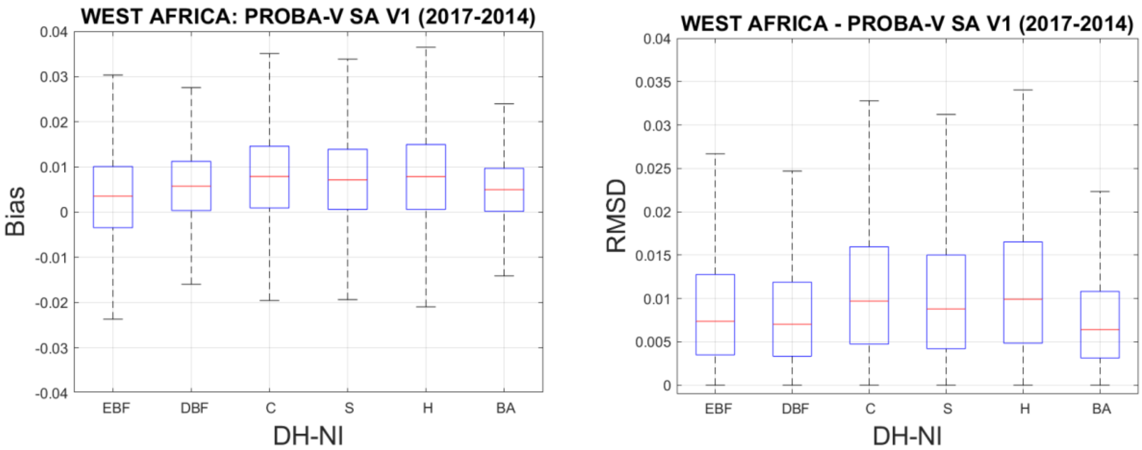


Figure 42: As in Figure 41 for AL-DH-NI.

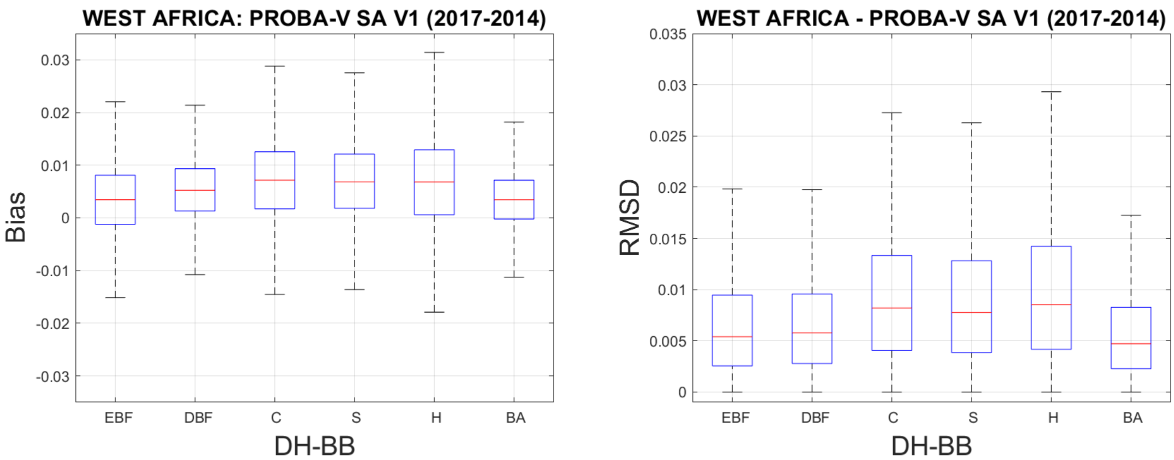


Figure 43: As in Figure 41 for AL-DH-BB.

The main conclusions are:

- Similar trends were observed for all spectral ranges (visible, NIR and total shortwave). Median values are slight positive (2017>2014) for all biome type, typically 0.005 in all cases. The best performance was found for Bare Areas, with median bias close to zero and low scattering, showing typically more than 50% of data bias lower than 0.01.
- The median RMSD values are lower than 0.0075 for AL-DH-VI, and lower than 0.01 for AL-DH-NI and AL-DH-BB for all biome types.

5.3 ACCURACY ASSESSMENT

To investigate the accuracy of PROBA-V SA V1.5 (and MODIS C6 for benchmarking) satellite albedo products ("blue-sky" albedo), scatter plots versus field measurements were produced for the whole 2017 year over 5 NEON sites (see section 4.3). This exercise was performed at the primary spatial resolution of each satellite products (i.e 1km in case of PROBA-V, and 500m in case of MODIS C6), considering only sites homogeneous of, at least, 1 km^2 footprint area around the albedo in-situ station. Temporal averages of daily ground data was performed to compare with satellite estimations, considering the different composite approach of each satellite product (i.e 30 days in case of PROBA-V, and 16 days in case of MODIS C6). This analysis was carried out for snow free conditions. For this purpose, temporal averages showing snow ground values (blue-sky albedo measurements higher than 0.5) during the temporal composite period were not considered. Furthermore, PROBA-V and MODIS C6 pixels flagged as 'low' quality in the Quality Flag (Table 9) were also rejected from the computation.

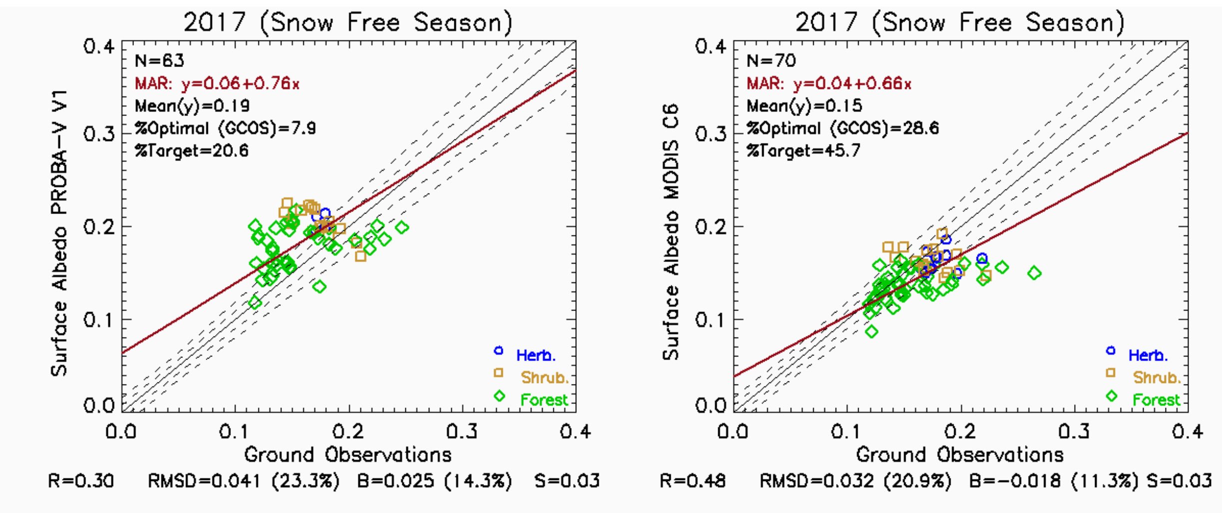


Figure 44: Accuracy Assessment of PROBA-V SA V1 Collection 1km (left) and MODIS MCD43A3 C6 (right) blue-sky albedo satellite products versus ground values coming from 5 NEON stations during the 2017 year for Snow Free conditions. Continuous black line corresponds to 1:1 line and dashed lines to optimal (GCOS uncertainty requirement) and target levels. Red line corresponds to the Major Axis Regression (MAR).

Table 13: Relevant statistics of the Accuracy Assessment of PROBA-V SA V1 Collection 1km (left) and MODIS MCD43A3 C6 (right) blue-sky albedo satellite products versus ground values coming from 5 NEON stations during the 2017 year for Snow Free conditions. Percentage of samples lying within the pre-defined uncertainty levels of optimal (GCOS), target and threshold (Table 5) are showed.

	NEON (2017)	
	PROBA-V SA V1.5	MCD43A3 C6
N	63	70
Correlation (R)	0.3	0.48
Bias	0.025 (14.3%)	-0.018 (11.3%)
RMSD	0.041 (23.3%)	0.032 (20.9%)
Offset (MAR)	0.06	0.04
Slope (MAR)	0.76	0.66
%Optimal (GCOS)	7.9	28.6
%Target (CGLOPS optimal)	20.6	45.7
%Threshold (CGLOPS target)	54	71.4

The main conclusions from scatter-plots (Figure 44) and associated metrics (Table 13) are:

- Overall accuracy of RMSD=0.041 was found for PROBA-V SA V1 products, showing worse results in terms of RMSD than MODIS C6 (RMSD=0.032). Identical RMSD of PROBA-V was found for PROBA-V SA V1 over 17 SURFRAD and EFDC sites during 2014 year in the validation report [CGLOPS1_VR_SA1km-PROBAV-V1.5]. Furthermore, MODIS C6 results are also consistent with previous validation exercises of MODIS C5 over SURFRAD sites (Jin, Y. et al., 2003; Liu, J. et al., 2009), as well as the observed in the validation report during the 2014 year.
- Positive bias of 0.025 (14.3%) of PROBA-V SA Collection 1km was found, as observed on the temporal profiles in section 5.2.2.3. This positive bias was found for albedo values up to 0.2, confirming the main finding of the validation report [CGLOPS1_VR_SA1km-PROBAV-V1.5]. MODIS C6 showed slight improved results in terms of bias, showing low negative bias of -0.018 (11.3%).
- Only 7.9% of 53 PROBA-V samples achieved the GCOS uncertainty requirements, whereas MODIS C6 provides improved results (28.6%). User requirements from the technical user group of the Copernicus Global Land seem to be more realistic, showing in case of PROBA-V 20.6% and 54% of cases within the GGLOPS optimal and target level (45.7% and 71.4% in case of MODIS C6).

6 CONCLUSIONS

The scientific quality evaluation of the PROBA-V SA Collection 1km V1 products during the whole 2017 year was conducted, following the procedures described in the Global Land Service Validation Plan [CGLOPS1_SVP]. The main objective was to demonstrate that the recent (2017) PROBA-V products keep the same quality level than the validated PROBA-V products (2014). SPOT/VGT SA V1 products during the 2012 year were also included in the study. At global scale, several criteria of performance were evaluated, including completeness, spatial and temporal consistency, smoothness (intra-annual precision), inter-annual precision. Furthermore, the quality of the PROBA-V SA product was evaluated over West Africa, performing the analysis per biome type. In addition, realism of temporal trajectories was evaluated over specific fire events and sites with available ground measurements, including similar MODIS C6 products for benchmarking. Finally, the accuracy of PROBA-V SA V1 and MODIS C6 was evaluated over ground data coming from 5 NEON stations. The main conclusions are summarized below:

Product Completeness

- The spatio-temporal continuity of PROBA-V SA products is poor over latitudes higher than 45º North and over the equatorial belt, showing similar spatial distribution of gaps between 2017 and 2014 years. The temporal evolution of the gaps was also found consistent between 2017 and 2014 years, showing slight better fraction of valid data in 2017 during winter period in northern hemisphere.
- The length of gaps of PROBA-V SA was also consistent between recent 2017 and validated PROBA-V 2014 and SPOT/VGT 2012 years.

Spatial Consistency

- Global maps and regional maps over West Africa region of PROBA-V SA products showed consistent distribution of values between recent (2017) and validated (2014) PROBA-V SA products, without finding spatial artefacts.
- Only a sharp latitudinal transition around 50ºN was observed during winter time, in line with the previous validation findings [CGLOPS1_VR_SA1km-PROBAV-V1.5] explained by consequence of the known limitations of PROBA-V cloud detection algorithm [probav_cloudmask_validation_v1.0.pdf].

Temporal Consistency

- Globally, the cross-correlations, computed over LANDVAL sites, between 2017 and 2014 PROBA-V SA V1 temporal variations, were higher than 0.7 typically in more than 40% for most of the biome types except for Herbaceous (all spectral domains) and Bare Areas (visible domain). Poor cross-correlations were found for EBF.

- Similar temporal trend was also found between 2017 and 2014 PROBA-V temporal variations for averaged values per biome type over the West Africa region.
- Temporal variations of PROBA-V V1 provides similar temporal trends than MODIS C6 for most of the sites showing specific fire events during the 2017 year, as well as over 5 sites with availability of ground data coming from NEON stations. However, most of the snow events detected in the ground data were not properly captured by both satellite products.

Inter- Annual Precision

- PROBA-V V1 recent products (2017) versus validated PROBA-V V1 products (2014) show median absolute deviation of anomalies of 0.007 (4.2%), 0.015 (4.5%) and 0.009 (3.6%) for visible, NIR and total shortwave.
- Comparison between recent (2017) and validated (2014) products over desertic calibration sites showed mean bias of 0 for visible domain, 0.9% for NIR and 0.7% for the shortwave, and RMSD around 2 – 3%, achieving the GCOS requirements in terms of stability (1%) in terms of mean bias.

Intra- Annual Precision

- Recent PROBA-V SA 1km V1 (all spectral channels) products showed that the precision at short time scale is preserved during the 2017 year, with almost identical intra-annual precision (smoothness) of the equivalent period of PROBA-V and SPOT/VGT for previous 2014 and 2012 years, respectively.

Overall Spatio-Temporal Consistency

- The comparison of recent PROBA-V SA V1 (2017) and validated (2014) years showed:
  - Good spatio-temporal consistency (offset ~0 and slope ~1) over LANDVAL sites, with very low bias of -0.5%, 1.7% and 1.4% of AL-DH-VI, AL-DH-NI and AL-DH-BB. Low RMSD values were found (0.057 for AL-DH-VI, 0.035 for AL-DH-NI and 0.042 for AL-DH-BB), with higher correlations (R>0.9). Around 50% of LANDVAL pixels showed optimal consistency for NIR and total shortwave, and around 32% in case of the visible domain.
  - Distribution of retrievals per biome type, over LANDVAL sites showed almost identical distribution of retrievals between 2017 and 2014 PROBA-V SA products (all spectral channels) for all biome type and spectral domain, with only some differences in snow pixels.
  - Over the West Africa region, PROBA-V recent 2017 and validated 2014 years were found consistent, with median bias typically around 0.005 for all biome type and spectral domain, and median RMSD lower than 0.0075 in case of visible domain, and lower than 0.01 for NIR and total shortwave for all biome types.

- PROBA-V SA V1 (2017) versus SPOT/VGT products (2012):
  - The comparison over LANDVAL sites of recent PROBA-V SA V1 (2017) products and reference SPOT/VGT products (2012) confirms the positive bias of SA V1 products when changing the sensor from SPOT/VGT to PROBA-V for NIR and total shortwave [CGLOPS1_VR_SA1km-PROBAV-V1.5]. PROBA-V 2017 versus SPOT/VGT 2012 showed almost no mean bias of 1% for visible domain, and positive bias of 10.5% and 8.7% for NIR and total shortwave. RMSD values of 0.075, 0.052 and 0.055 were found for AL-DH-VI, AL-DH-NI and AL-DH-BB, with high correlations (R>0.85). Typically more than 20% of pixels showed optimal consistency, and more than 40% considering the target level.
  - Distribution of retrievals per biome type, over LANDVAL sites showed a clear tendency of PROBA-V to provide higher retrievals than SPOT/VGT for all biome type (except snow cases) in case of NIR and total shortwave.

Accuracy Assessment

- The comparison of PROBA-V SA V1 with field data coming from 5 NEON stations shows RMSD of 0.041 for the 2017 year, showing improved results in MODIS C6 (0.032). PROBA-V provides systematic overestimation (mean bias of 0.025, 14.3%), whereas MODIS C6 provides negative bias (-0.018, 11.3%).
- Very low percentage of PROBA-V pixels within the GCOS requirements was found (8% of 63 samples). In case of MODIS C6, 28.6% of pixels achieved the GCOS requirements.
- Regarding the percentage of cases achieving the user requirements from the technical user group of the Copernicus Global Land, 20.6% and 54% of cases are within the optimal and target level (45.7% and 71.4% in case of MODIS C6).

Concluding remarks

This Scientific Quality Evaluation demonstrates that the recent (2017) PROBA-V SA Collection 1km V1 products keep a similar level of quality than the validated (2014) products for all spectral channels. In overall, good quality was found for most of the criteria, with the main limitation of the positive bias observed in NIR, affecting also the total shortwave. The known limitations of the PROBA-V cloud masking algorithm also affect to the spatial consistency of PROBA-V SA products during winter time in northern latitudes.

Table 14 summarizes the main results:

Table 14: Summary of Product Evaluation (PROBA-V SA 1km V1). 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.
Spatial Consistency	±	Reliable and consistent values over the whole globe and over West-Africa, without observing spatial artefacts. The exception of good spatial consistency was the sharp latitudinal transition ~50º during winter season due to PROBA-V Collection 1 input data.
Temporal Consistency	+	Cross-correlations PROBA-V SA 2017vs2014, over LANDVAL, >0.7 in more than 40% for most of the cases. Poor cross-correlations were found for EBF. Similar temporal trajectories per biome type over West-Africa between PROBA-V SA 2017 and 2014. Similar temporal variations than MODIS C6 over specific fire events and sites with available ground measurements.
Intra-Annual Precision	+	Very low short-time variability (smooth temporal profiles) as in the validated period.
Inter-Annual Precision	±	Median absolute deviation of anomalies (95^{th} and 5^{th} percentiles) between PROBA-V (2017 vs 2014) of 0.007 (4.2%), 0.015 (4.5%) and 0.009 (3.6%) for visible, NIR and total shortwave. PROBA-V 2017 vs 2014 over desertic calibration sites showed mean bias lower than 1% (achieving GCOS stability requirements) and RMSD around 2 – 3%.
Overall Spatio-Temporal Consistency	±	**PROBA-V 2017 vs 2014:** RMSD=0.057/0.035/0.042 for AL-DH-VI/AL-DH-NI/AL-DH-BB Mean bias= -0.5%/1.7%/1.4% Similar distribution of retrievals for all biome types. **PROBA-V 2017 vs SPOT/VGT 2012:** RMSD=0.075/0.052/0.055 for AL-DH-VI/AL-DH-NI/AL-DH-BB Mean bias= 1%/10.5%/8.7%, confirming the positive bias when changing SPOT/VGT by PROBA-V input data. Systematic distribution towards higher values in PROBA-V for all biome type (NIR and BB), except in snow.
Accuracy Assessment	-	Over 5 NEON sties during 2017 year (snow free conditions): **PROBA-V**: N=63; B=0.025 (14.3%); RMSD=0.041; Snow free. 8% of pixels within GCOS. 20.6% and 54% within optimal and target levels from technical user group of the Copernicus Global Land. **MODIS C6**: N=70, B=-0.018 (11.3%); RMSD= 0.032; 28.6% of pixels within GCOS. 45.7% and 71.4% within optimal and target from technical user group of the Copernicus Global Land.

7 RECOMMENDATIONS

Our analysis shows an overall good result, showing that the quality of the recent PROBA-V SA collection 1km V1 products (2017) is preserved, compared with validated 2014 product.

However, for further improvements of the product, it is recommended to PROBA-V mission to reprocess the whole PROBA-V archive with an improved cloud detection algorithm.

It is also recommended to investigate and try to correct the systematic positive differences of PROBA-V compared to SPOT/VGT SA products in order to improve the consistency of the time series. This positive bias was mainly observed for NIR, and also affects to the total shortwave.

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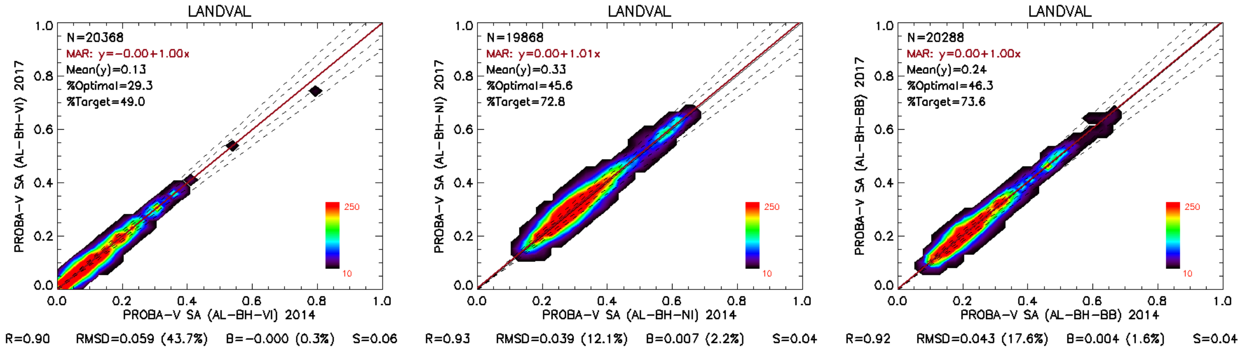
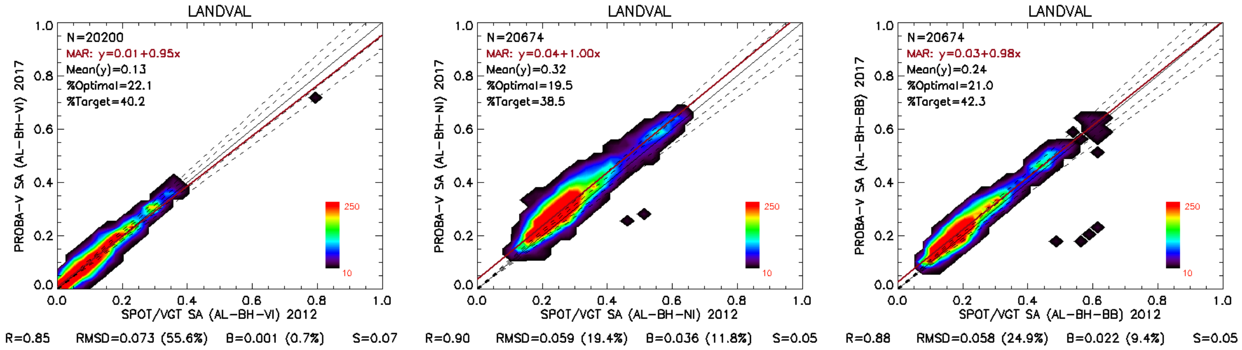
ANNEX I. OVERALL SPATIO-TEMPORAL CONSISTENCY OF AL-BH PRODUCTS

GLOBAL SCATTER-PLOTS

- **PROBA-V 2017 vs PROBA-V 2014**

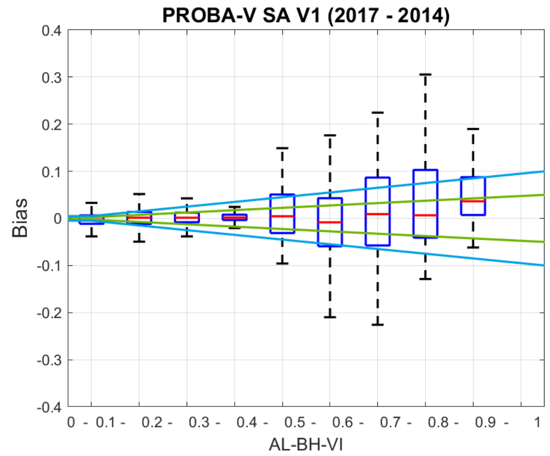


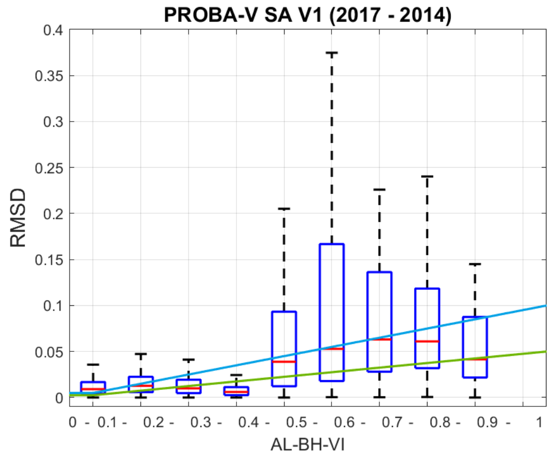
- **PROBA-V 2017 vs SPOT/VGT 2012**

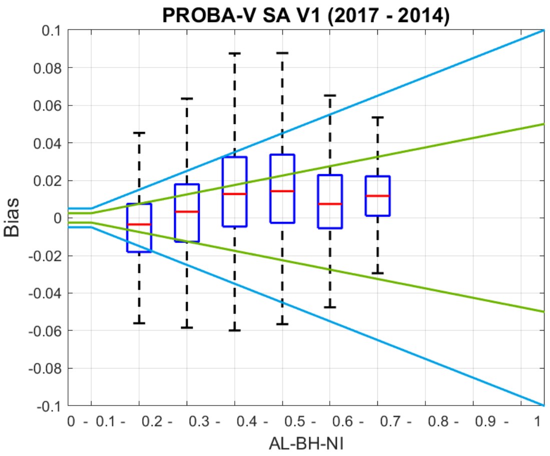


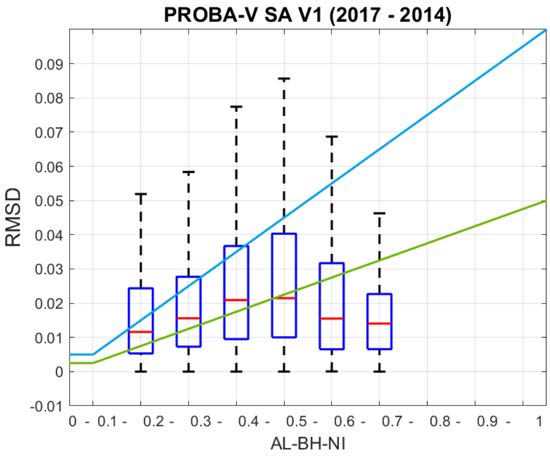
BOX-PLOT OF UNCERTAINTIES PER BIN

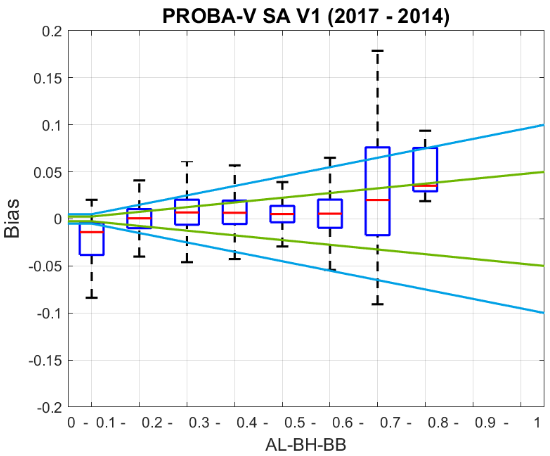
➢ PROBA-V 2017 vs PROBA-V 2014

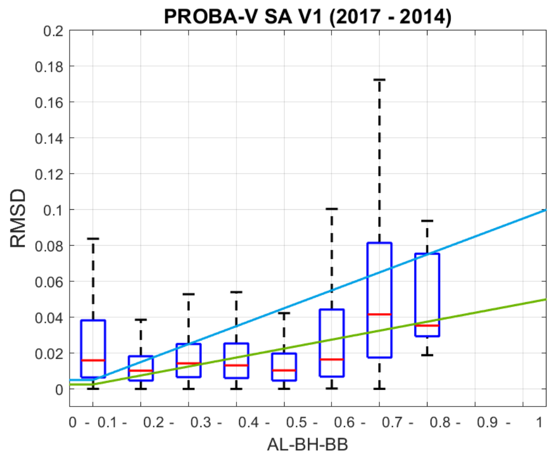




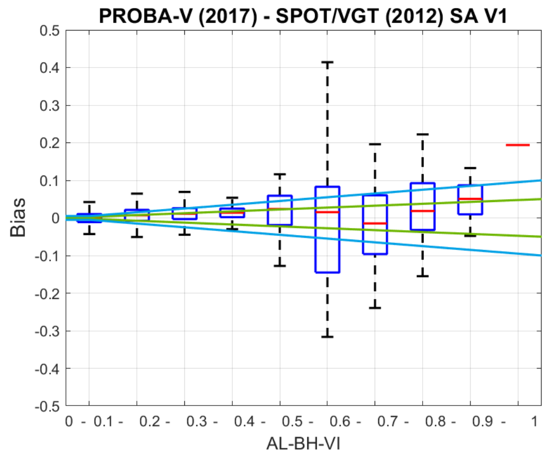


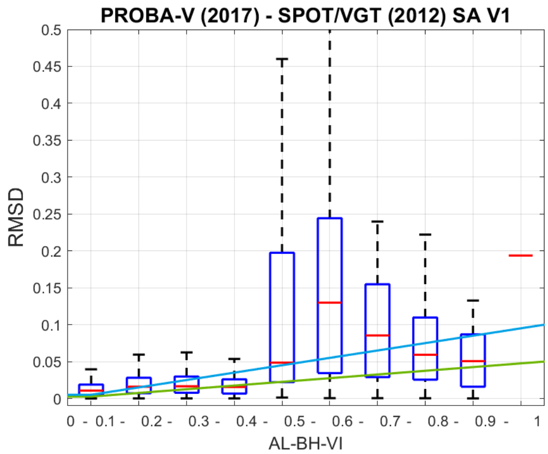


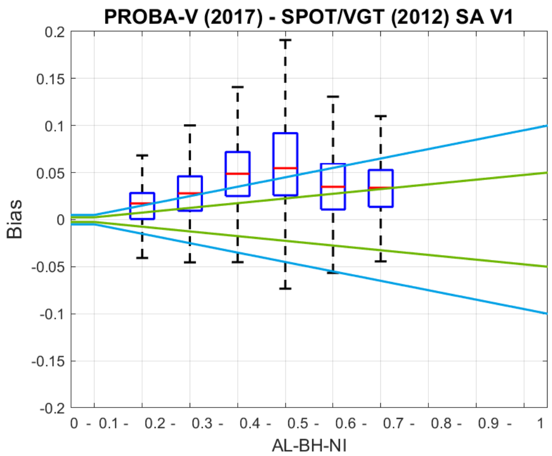


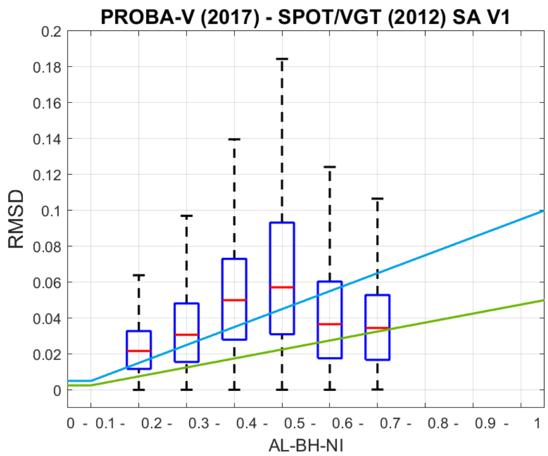


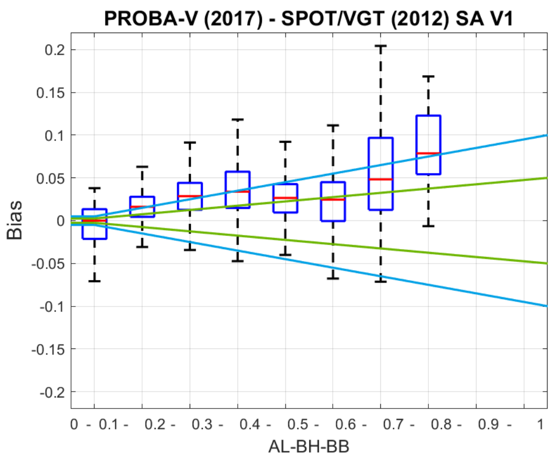
➢ **PROBA-V 2017 vs SPOT/VGT 2012**

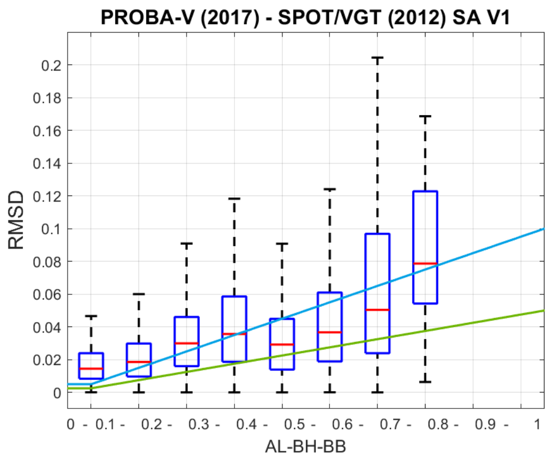






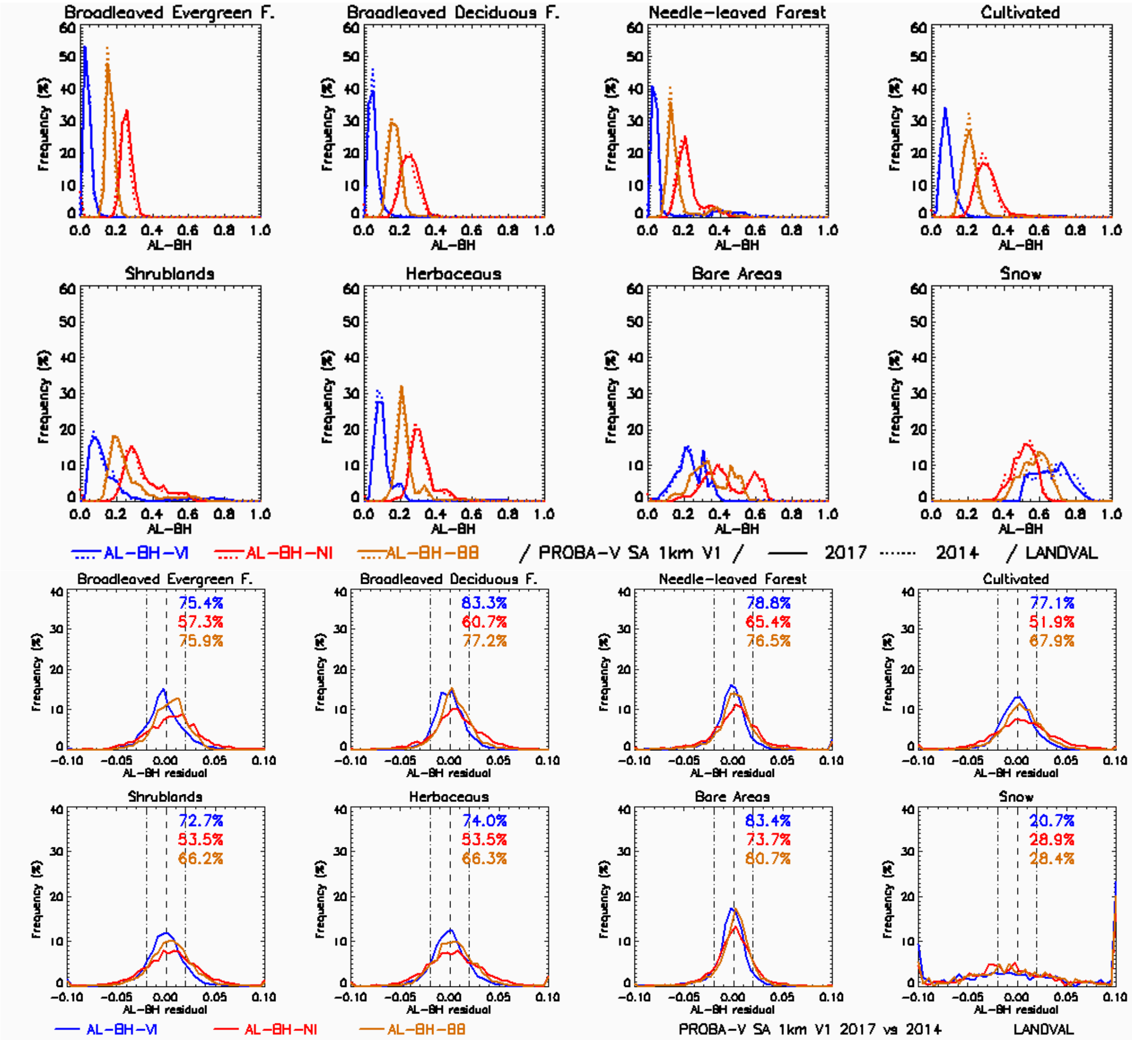




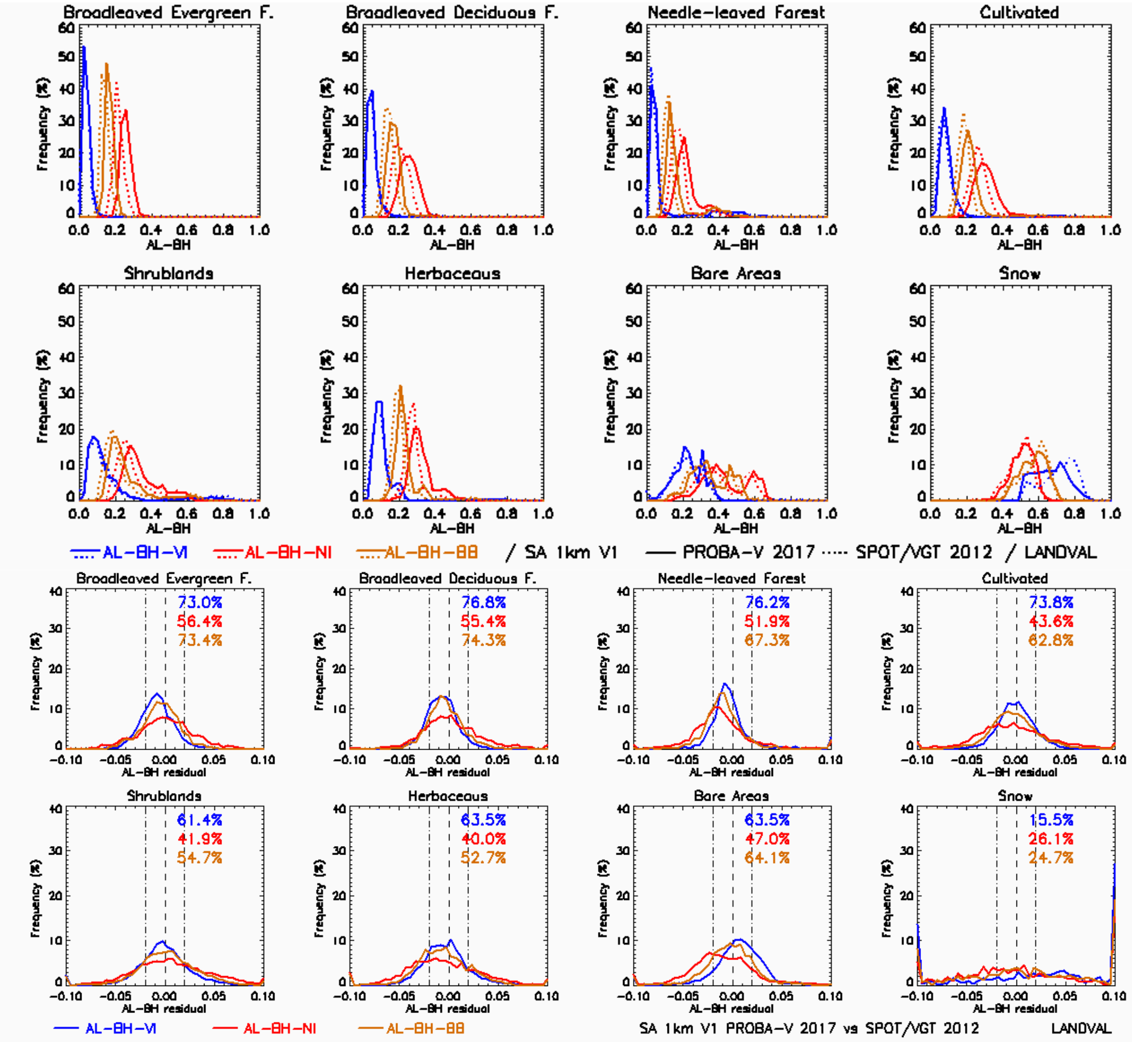


DISTRIBUTION OF RETRIEVALS AND RESIDUALS PER BIOME TYPE

➢ **PROBA-V 2017 vs PROBA-V 2014**

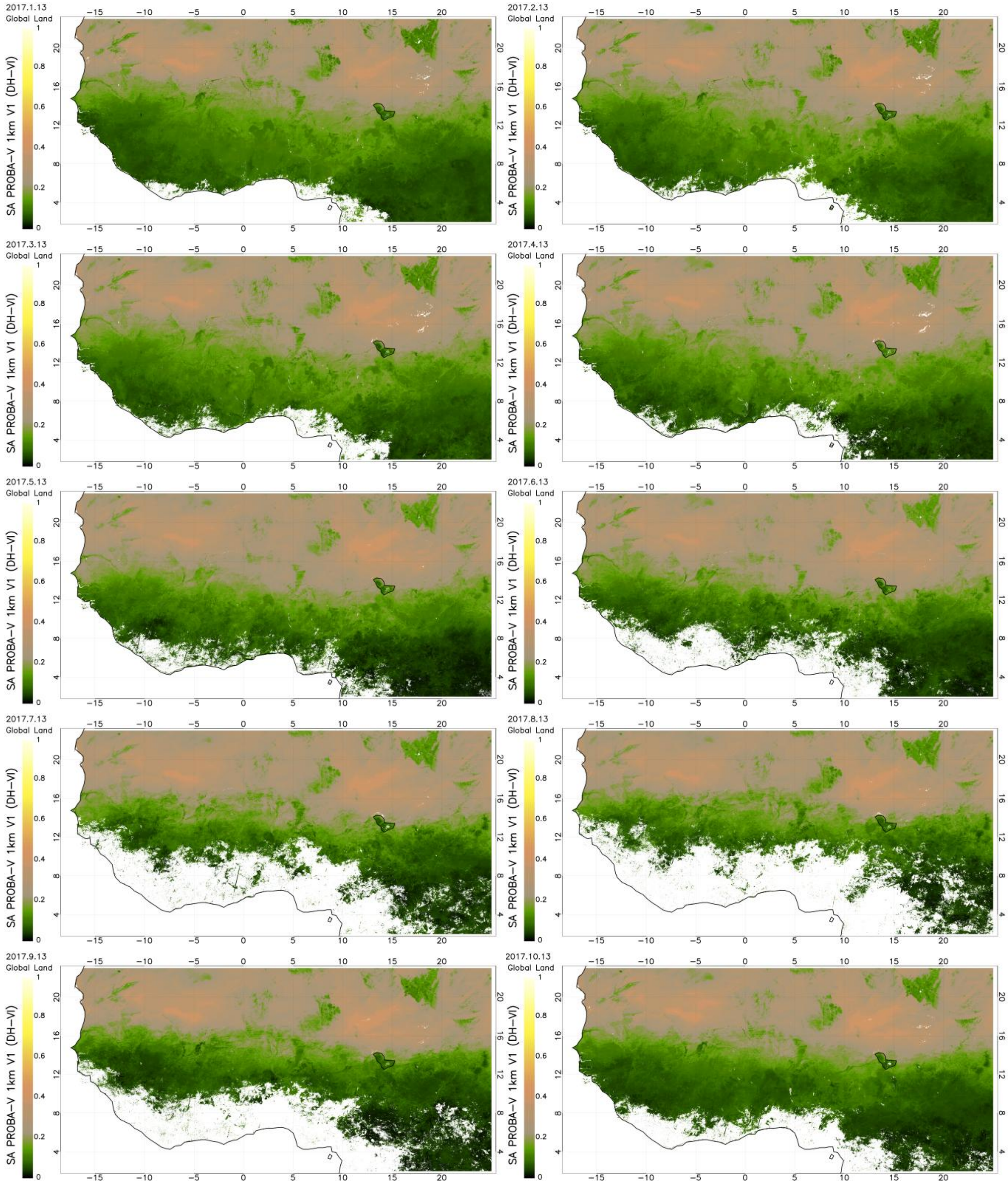


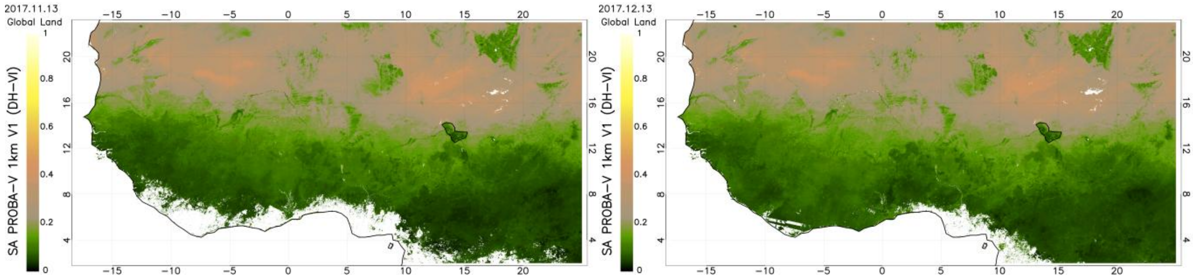
- **PROBA-V 2017 vs SPOT/VGT 2012**



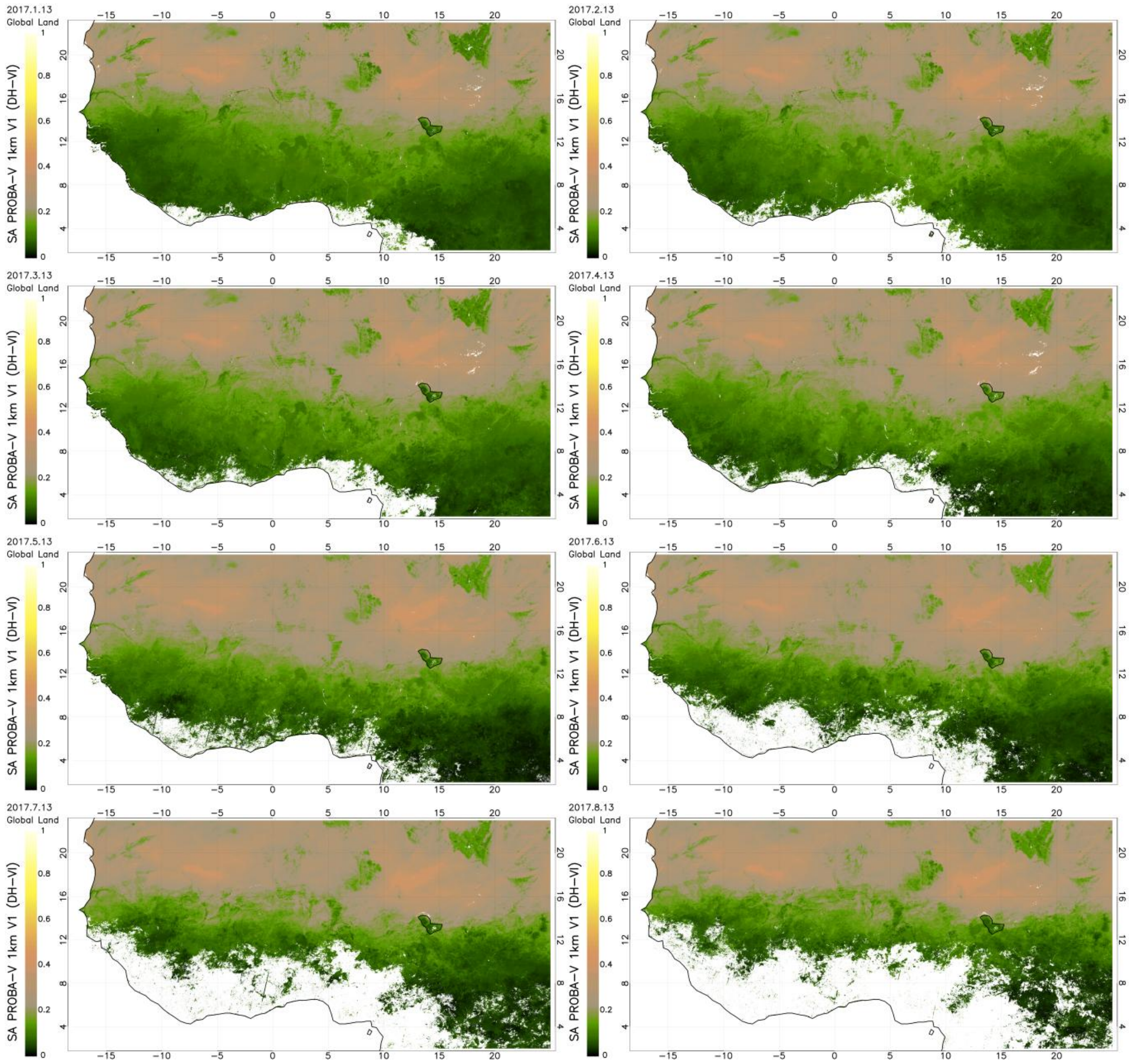
ANNEX II. MAPS OF PROBA-V SA V1 PRODUCTS OVER THE WEST AFRICAN SUB-CONTINENTAL REGION DURING THE 2017 YEAR

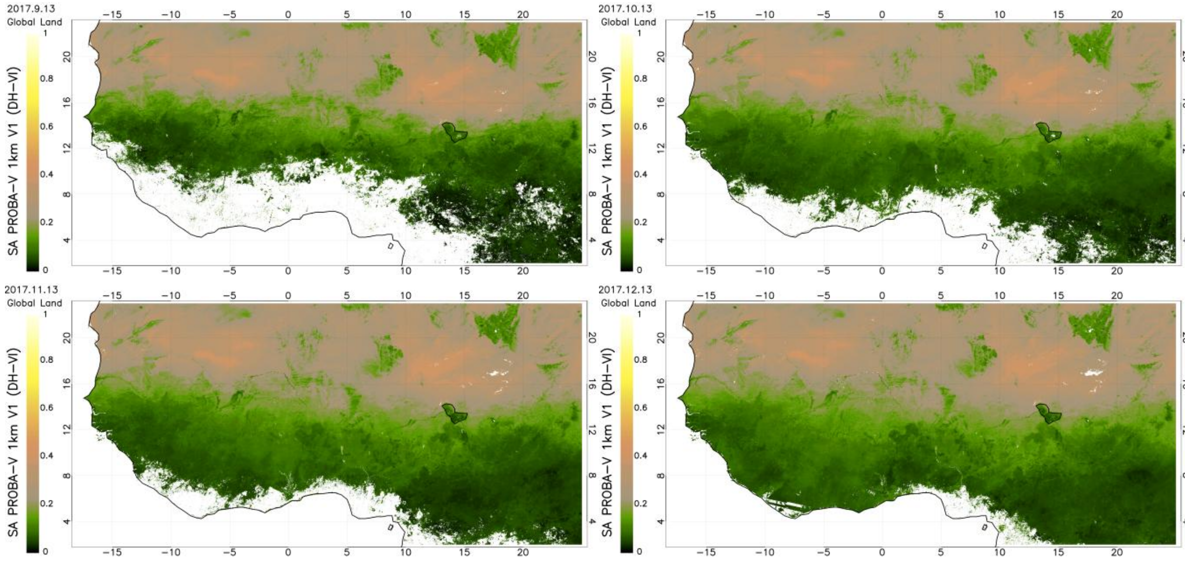
➢ AL-DH-VI



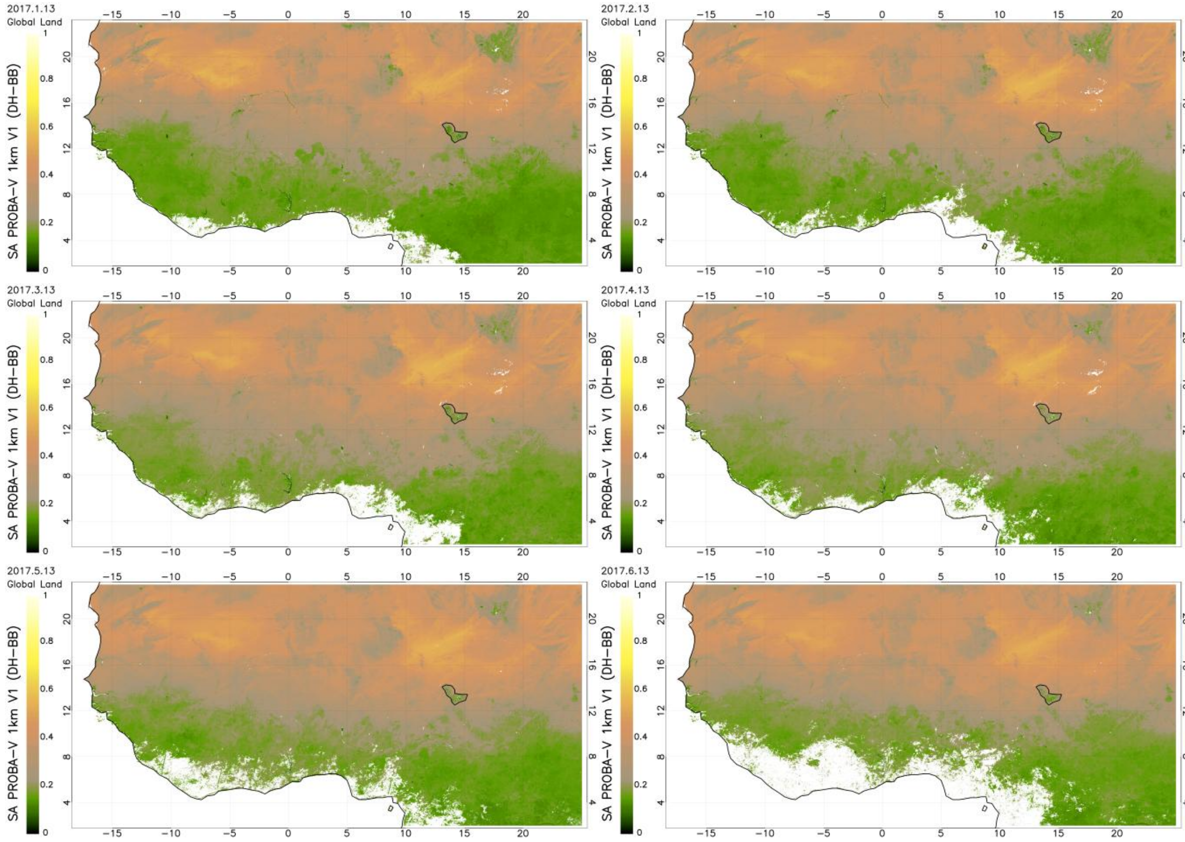

2017.11.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.12.13
Global Land
SA PROBA-V 1km V1 (DH-VI)

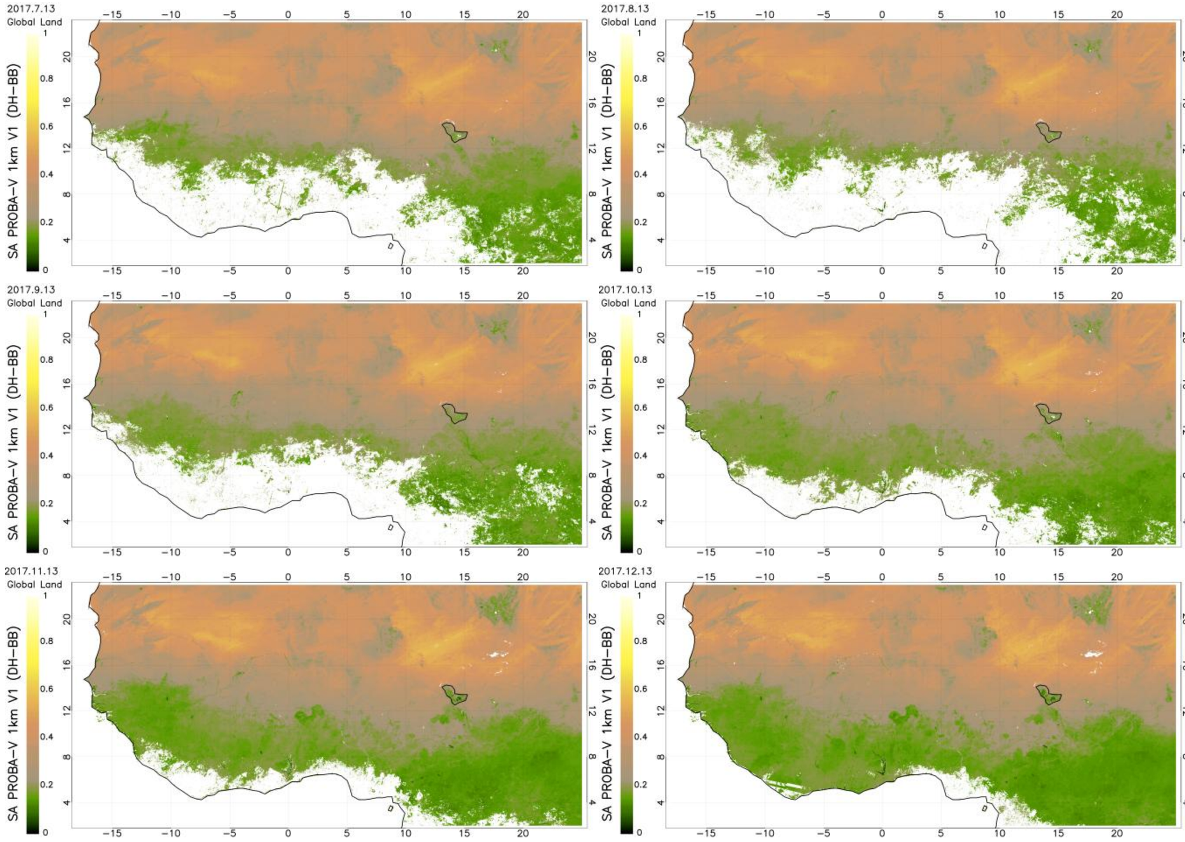
- **AL-DH-NI**


2017.1.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.2.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.3.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.4.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.5.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.6.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.7.13
Global Land
SA PROBA-V 1km V1 (DH-VI)
2017.8.13
Global Land
SA PROBA-V 1km V1 (DH-VI)

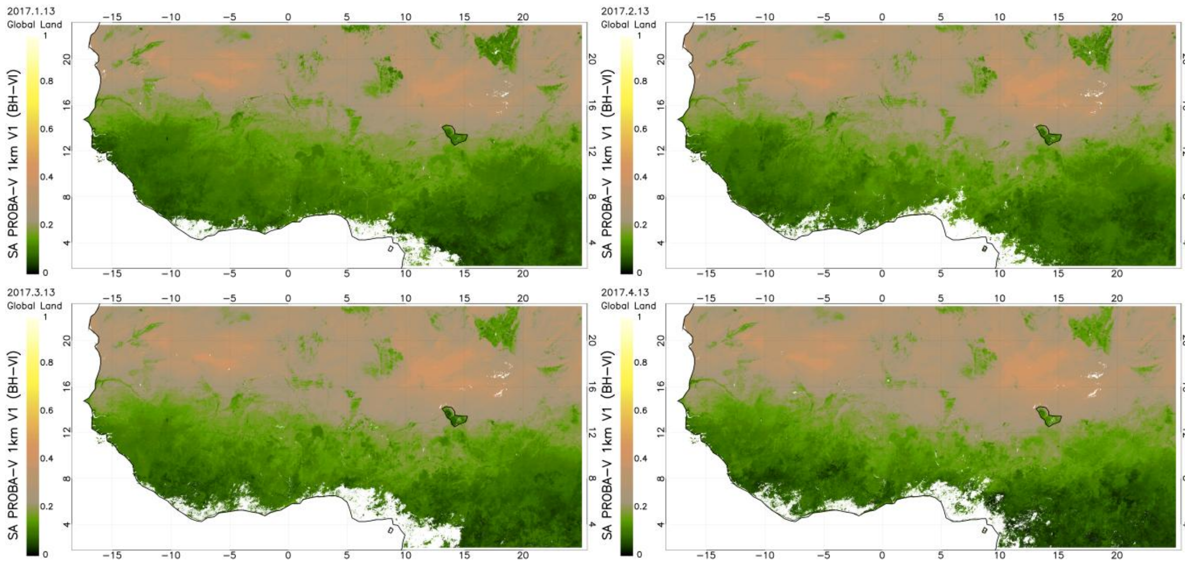

2017.9.13
Global Land
SA PROBA−V 1km V1 (DH−VI)
2017.10.13
Global Land
SA PROBA−V 1km V1 (DH−VI)
2017.11.13
Global Land
SA PROBA−V 1km V1 (DH−VI)
2017.12.13
Global Land
SA PROBA−V 1km V1 (DH−VI)

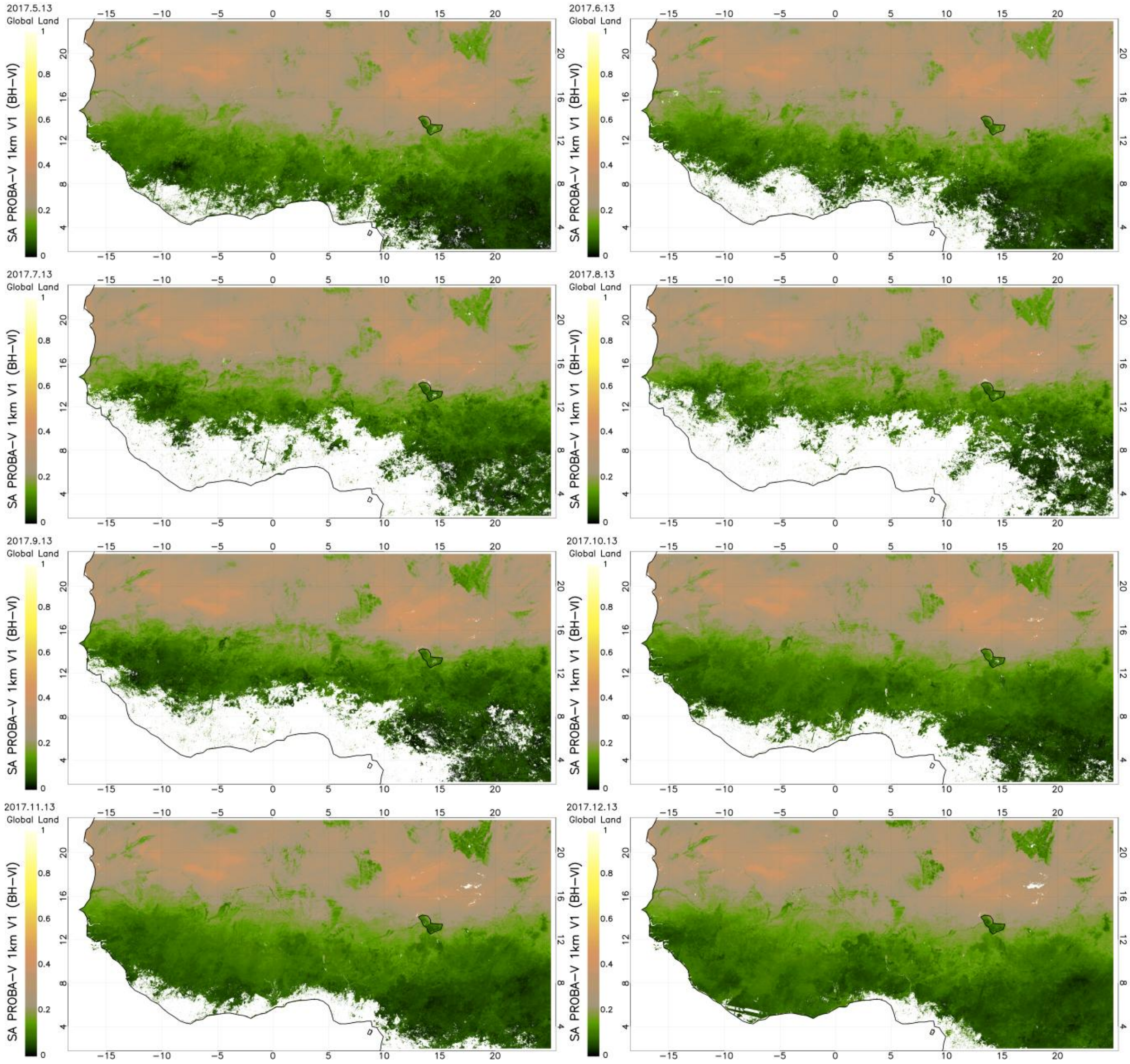
➢ AL-DH-BB


2017.1.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.2.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.3.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.4.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.5.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.6.13
Global Land
SA PROBA−V 1km V1 (DH−BB)

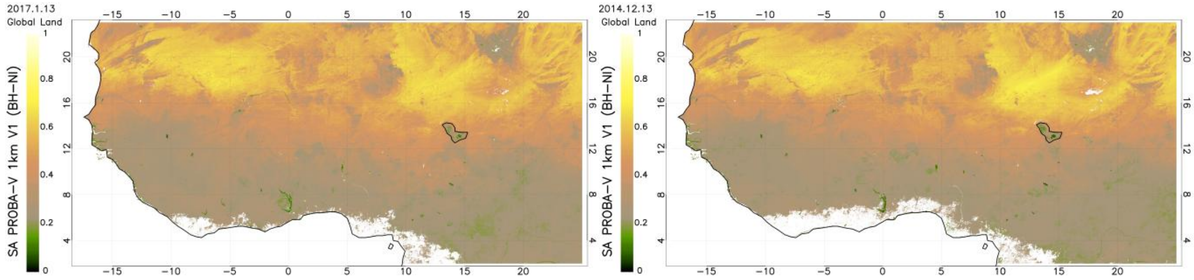

2017.7.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.8.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.9.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.10.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.11.13
Global Land
SA PROBA−V 1km V1 (DH−BB)
2017.12.13
Global Land
SA PROBA−V 1km V1 (DH−BB)

➢ AL-BH-VI


2017.1.13
Global Land
SA PROBA−V 1km V1 (BH−VI)
2017.2.13
Global Land
SA PROBA−V 1km V1 (BH−VI)
2017.3.13
Global Land
SA PROBA−V 1km V1 (BH−VI)
2017.4.13
Global Land
SA PROBA−V 1km V1 (BH−VI)


2017.5.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.6.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.7.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.8.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.9.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.10.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.11.13
Global Land
SA PROBA-V 1km V1 (BH-VI)
2017.12.13
Global Land
SA PROBA-V 1km V1 (BH-VI)

- **AL-BH-NI**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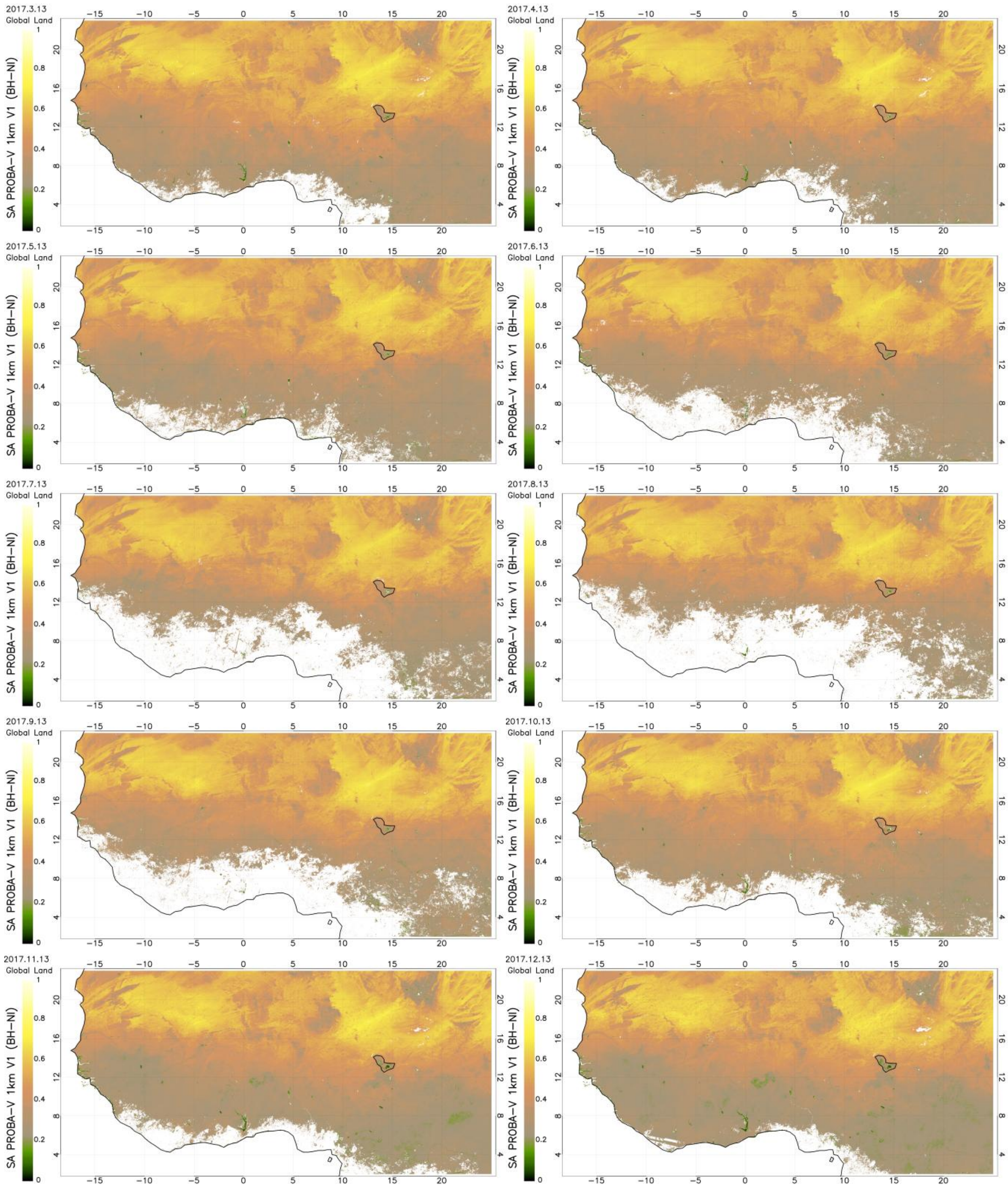
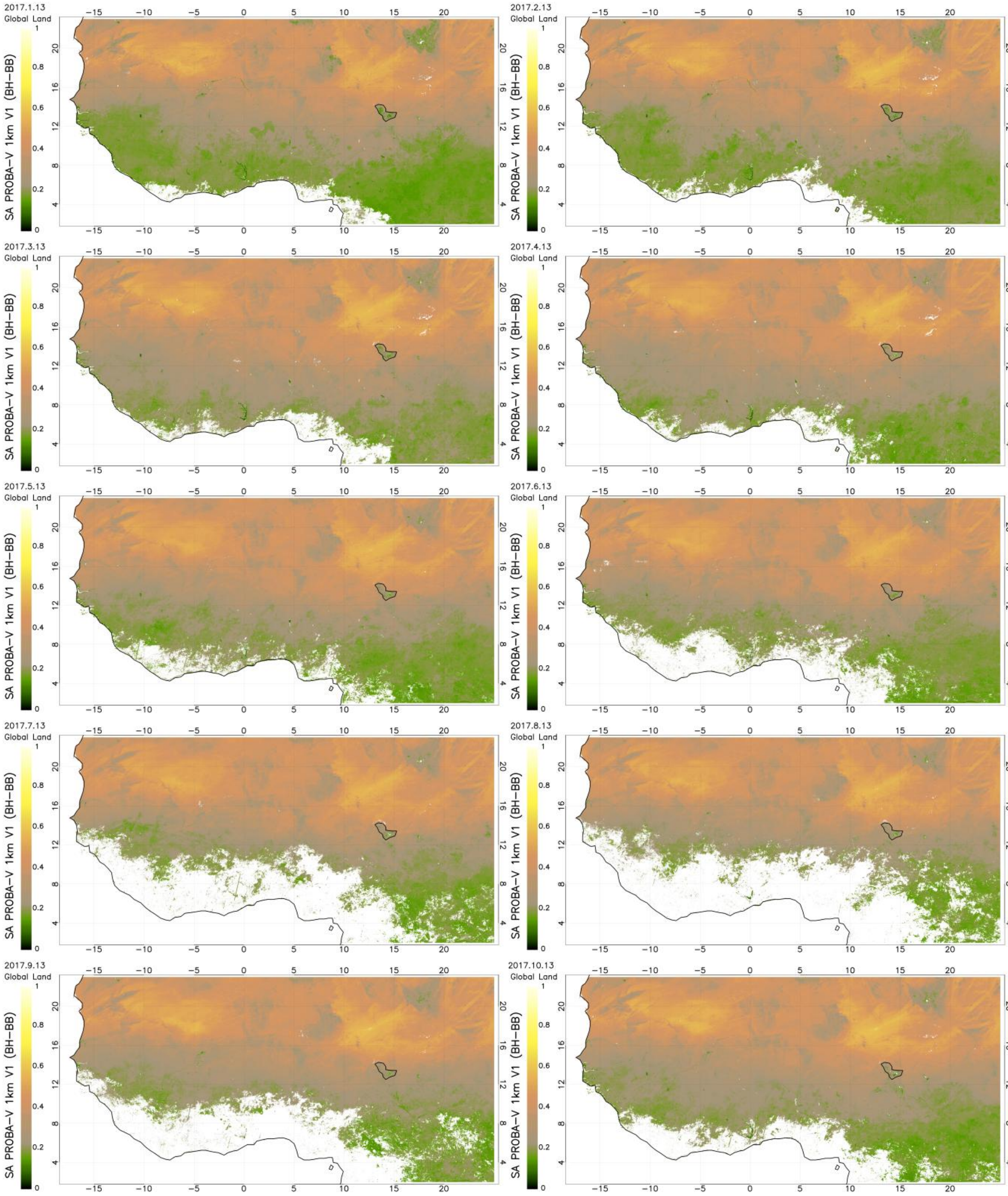
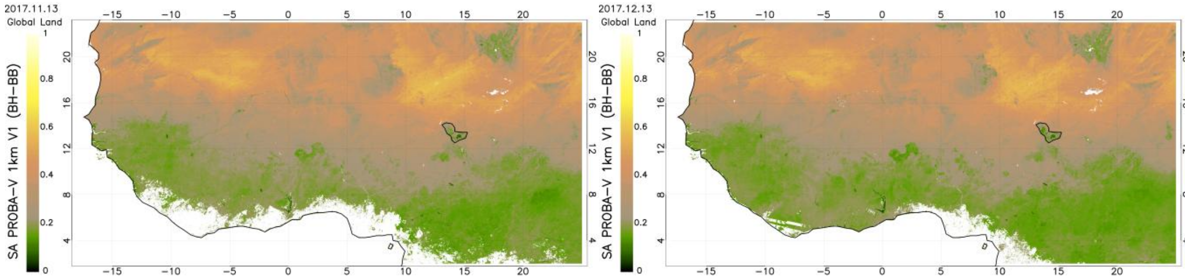
Global Land
SA PROBA-V 1km V1 (BH-NI)
2014.12.13
Global Land
SA PROBA-V 1km V1 (BH-NI)


2017.3.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.4.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.5.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.6.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.7.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.8.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.9.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.10.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.11.13
Global Land
SA PROBA-V 1km V1 (BH-NI)
2017.12.13
Global Land
SA PROBA-V 1km V1 (BH-NI)

➢ AL-BH-BB


2017.1.13
Global Land
2017.2.13
Global Land
2017.3.13
Global Land
2017.4.13
Global Land
2017.5.13
Global Land
2017.6.13
Global Land
2017.7.13
Global Land
2017.8.13
Global Land
2017.9.13
Global Land
2017.10.13
Global Land
SA PROBA−V 1km V1 (BH−BB)


2017.11.13
Global Land
SA PROBA−V 1km V1 (BH−BB)
2017.12.13
Global Land
SA PROBA−V 1km V1 (BH−BB)