Copernicus Global Land Operations "Vegetation and Energy"

"CGLOPS-1"

Framework Service Contract N° 199494 (JRC)

VALIDATION REPORT

SURFACE ALBEDO (SA) FROM PROBA-V

COLLECTION 1KM

VERSION 1.5

Issue I2.21

Organization name of lead contractor for this deliverable: EOLAB

Book Captain: Jorge Sánchez-Zapero
Contributing Authors: Lorena de la Madrid
Fernando Camacho

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

Document Release Sheet

Book captain:	Jorge Sánchez-Zapero	Sign	Date 20.07.2018
Approval:	Roselyne Lacaze	Sign	Date 20.07.2018
Endorsement:	Michael Cherlet	Sign	Date
Distribution:	Public		

Change Record

Issue/Rev	Date	Page(s)	Description of Change	Release
	30.03.2015	All	Quality assessment of Collection 1km Surface Albedo derived from PROBA-V	I1.00
I1.00	12.01.2018	All	Quality assessment of Collection 1km Surface Albedo derived from PROBA-V, after improvement of limitations identified in I1.00	I2.00
I2.00	08.02.2018		Finalisation for public release	I2.10
I2.10	16.07.2018	All	Update according to external reviewer's comments	I2.20
I2.21	20.07.2018	15, 47, 82, 91	Minor editorial corrections	I2.21

TABLE OF CONTENTS

List of Figures

List of Tables

List of Acronyms

AERONET	AErosol RObotic NETwork
AD	Applicable Document
AFRI	African continental region
ALBEDOVAL	ALBEDO VALidation study
AL-BH	White-sky albedo (Bi-Hemispherical ALbedo)
AL-DH	Black-sky albedo (Directional ALbedo)
AOI	Area Of Interest
AsiaFlux	Regional research FLUXNET network in Asia
ATBD	Algorithm Theoretical Basis Document
BA	Bare Areas
BELMANIP	Benchmark Land Multisite Analysis and Intercomparison of Products
BRDF	Bidirectional Reflectance Distribution Function
BSRN	Baseline Surface Radiation Network
BB	Broad Band
C	Cultivated
CAL/VAL	CALibration/VALidation
CCI	Climate Change Initiative
CEOS	Committee on Earth Observation Satellite
CGLOPS	Copernicus Global Land Operations
CGLS	Copernicus Global Land Services
CNES	Centre National d'Etudes Spatiales
CNRM	Centre National de Recherches Météorologiques
CV	Coefficient of Variability
CYCLOPES	Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites
DBF	Deciduous Broadleaf Forest
EBF	Evergreen Broadleaf Forest
EC	European Commission
ECV	Essential Climate Variable
EFDC	European Fluxes Database Cluster
EO	Earth Observation
EOLAB	Earth Observation LABoratory
EOS	Earth Observation System
ERR	ERRor (Uncertainty ancillary layer)
EURO	European continental region
FLUXNET	FLUXes NETwork (network of regional networks)
FOV	Field Of View
FP5	Fifth Framework Programme
FP7	Seventh Framework Programme
GCOS	Global Climate Observing System
GIO	Global Land Initial Operations
GLC2000	Global Land cover Classification
GSD	Ground Sampling Distance
H	Herbaceous
ImagineS	Implementation of Multi-scale Agricultural Indicators Exploiting Sentinels
JRC	Joint Research Center
LAI	Leaf Area Index
LANDVAL	LAND VALidation network

LPV	Land Product Validation (CEOS)
LTER	The Long Term Ecological Research Network
MAR	Major Axis Regression
MCD	MODIS products from Terra+Aqua
MI	Moran's Index
MODIS	MODerate resolution Imaging Spectroradiometer
MODTRAN	MODerate resolution atmospheric TRANsmition
NARMA	Natural Resource Monitoring in Africa
NASA	National Aeronautics and Space Agency
NI	Near Infra-Red
NIR	Near Infra-Red
NLF	Needle leaf Forest
NMOD	NuMber of valid Observations During the synthesis period
NOAM	North American continental region
OCEA	Oceania continental region
OLIVE	On Line Validation Exercise
OLS	Ordinary Least Squares
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
QA	Quality Assessment
QAR	Quality Assessment Report
QA4EO	Quality Assurance framework for Earth Observation
QA4ECV	Quality Assurance for Essential Climate Variable
QFLAG	Quality Flag
R	Correlation Coefficient
RMSD	Root Mean Square Deviation
S	Shrublands
SA	Surface Albedo
SAFARI2000	Southern African Regional Science Initiative experiment
SALVAL	Surface ALbedo VALidation tool
SAVS	Surface Albedo Validation Sites
SOAM	South American continental region
SPOT/VGT	Satellite Pour l'Observation de la Terre / VEGETATION
SURFRAD	SURFace RADiation Network
SVP	Service Validation Plan
SWIR	Short-Wave Infra-Red
TOC	Top Of Canopy
TOC-r	TOC reflectances
VI	Visible domain
WMO	World Meteorological Organization

EXECUTIVE SUMMARY

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

Many of the products of the Global Land Service were derived from SPOT/VEGETATION sensor data which has been switch off at the end of May 2014. To ensure the continuity of the service at 1km, the methodologies and the processing lines have been adapted to the data of the PROBA-V sensor. This report shows the quality assessment of PROBA-V surface albedo (SA) Collection 1km version 1.5 products during more than one year of data (November 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. 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.

Based upon these results, the products have reached a good quality in most of the criteria evaluated, with some drawbacks identified that users must take carefully into account. 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.

1 BACKGROUND OF THE DOCUMENT

1.1 SCOPE AND OBJECTIVES

The document presents the results of the quality assessment of PROBA-V SA Collection 1km Version 1.5 product.

The quality assessment is performed on PROBA-V SA Collection 1km products (V1.5rc12) covering the whole globe every 10 days from the dekad of 2013.11.13 to the dekad of 2014.12.13.

The objective is to evaluate the scientific quality of PROBA-V SA products and to determine if they reach the required quality to be disseminated to users.

1.2 CONTENT OF THE DOCUMENT

This document is structured as follows:

- Chapter 2 recalls the users 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 SPOT/VGT & PROBA-V SA Collection 1km Version 1 product
GIOGL1_VR_SA1km-V1	Validation report of the SPOT/VGT surface albedo Collection 1km Version1.4 products.

1.3.3 Output

Document ID	**Descriptor**
CGLOPS1_PUM_SA1km-V1	Product User Manual summarizing all information about the SPOT/VGT & PROBA-V SA Collection 1km Version 1 product

1.3.4 External documents

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

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-154, 2011)	1 km	Daily to weekly	Max(5%; 0.0025)	Max(1%; 0.0001)
Black and White-sky albedo (GCOS-200, 2016)	200/500m	Daily	Max(5%; 0.0025)	Max(1%; 0.001)

In a recent update of the GCOS requirements [GCOS-200, 2016], there is a distinction between the products targeted for “adaptation” and “modeling” that results in different needs for the horizontal resolution. In CGLS, we focus on modeling requirements as they are the main users targeted (Table 1). Note, as well, that the figure for stability requirements in absolute term has been corrected (0.001 instead of 0.0001).

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

Table 2: 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 [source:https://www.wmo-sat.info/oscar/variables/view/54].

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

3 QUALITY ASSESSMENT METHOD

3.1 OVERVALL PROCEDURE

The quality assessment follows the procedures described in the CGLS Service Validation Plan [CGLOPS1_SVP]. The protocols and metrics were defined to be consistent with the Land Product Validation (LPV) group of the Committee on Earth Observation Satellite (CEOS) for the validation of satellite-derived land product. Several criteria of performance were considered in agreement with previous global validation exercises (Camacho et al., 2013; Garrigues et al., 2008; Weiss et al., 2007), the OLIVE (On Line Validation Exercise) tool hosted by CEOS CAL/VAL portal (Weiss et al., 2014), and with the recent CEOS LPV Global LAI product validation good practices (Fernandes et al., 2014). EOLAB has developed the Surface ALbedo VALidation(SALVAL) tool (Sánchez-Zapero et al. 2017) to provide most of the validation and intercomparison results. SALVAL has two main objectives:

1. to provide transparency and traceability in the validation procedure, designed to be compliant with the CEOS-LPV sub-group and QA4EO recommendations,
2. to provide a tool to benchmark new products or update product validation results as the time series expands, reaching Validation Stage 4 in the CEOS LPV hierarchy.

Results from SALVAL allow evaluating the fitness-for-purpose according to the optimal and target requirements.

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, biome and continental region, 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 pattern of artefacts (e.g., missing values, stripes, unrealistic low values, etc.) can be achieved through systematic visual analysis of all global maps based on the expert knowledge of the scientist. The methodology for visual analysis includes the visualization of zoom over sub-continental areas (20º latitude x 30º longitude) at full resolution (see Figure 1), and the visualization of animations of global maps at a reduced (1/16 pixels) resolution.

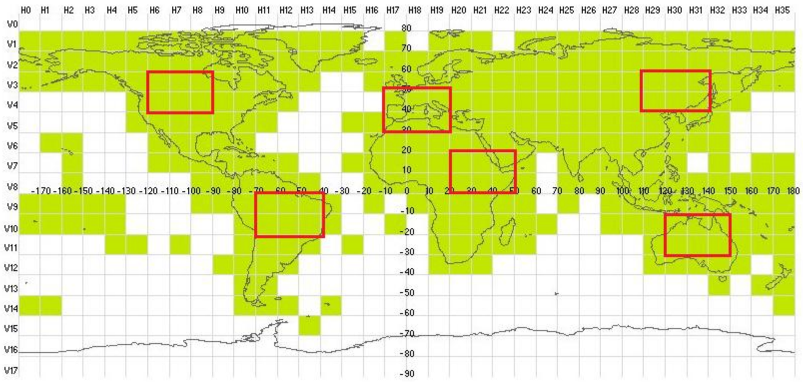


Figure 1: Location of the zoom areas displayed at full resolution for visual inspection of spatial consistency.

The spatial consistency can be quantitatively assessed by comparing the spatial distribution of a reference validated product with the product biophysical maps under study. Global maps of residuals at a reduced (1/6 pixels) resolution between the product under study and reference products are analyzed in order to identify regions showing spatial inconsistencies for further analysis (e.g. temporal profiles). Furthermore, histograms of residuals and percentage of residuals lying under the uncertainty levels (Figure 2, Table 4) are analyzed.

Here, two main levels of uncertainty (optimal and target) were defined, as described in Table 4. 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 (Table 2) and WMO breakthrough levels (10%, see Table 3). An additional threshold level of (0.02 for SA < 0.15 and 20% for SA > 0.15) was defined (equivalent to CGLOPS Target), so poor uncertainties correspond to values above this level. Figure 2 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 (optimal, target) are used. For surface albedo values higher than 0.05, relative values of 5%, 10% and 15% are used. In case of the threshold level, for surface albedo values lower than 0.15 absolute uncertainty of 0.03 was used whereas for values higher than 0.15 relative value of 20% was used.

Table 4: 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

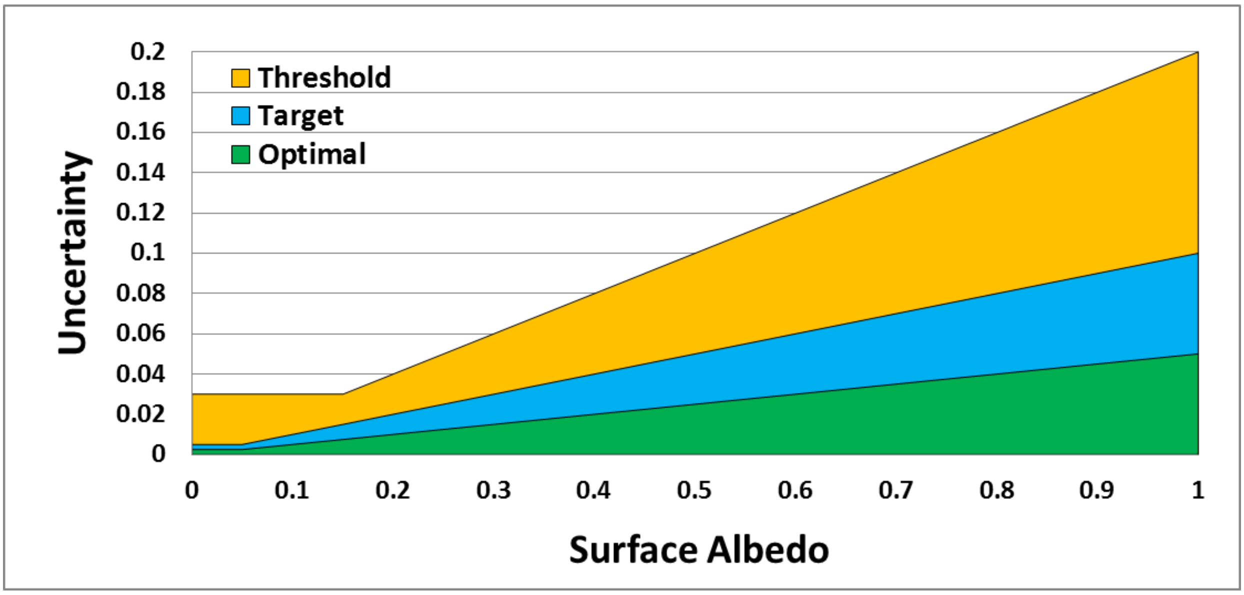


Figure 2: Uncertainty levels as a function of SA values.

Two products are considered spatially consistent when the residual lays within uncertainty requirements of the variable (see Table 4). The residual (ε) is 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. Table 5 and Figure 3 shows the linear equations used to compute the residuals between PROBA-V and SPOT/VGT. Very similar results were found for black-sky and white-sky albedos for each spectral domain. Note that for visible domain, very close relationships to the 1:1 line were found for the whole range, which means that residuals are very close to differences.

Table 5: Major Axis Regression relationship between PROBA-V and SPOT/VGT SA products during December 2013 to May 2014, computed over LANDVAL network of sites.

		VI	NI	BB
MAR PROBA-V vs SPOT/VGT	AL-DH	y=0.003+x	y=0.023+0.97x	y=0.011+x
	AL-BH	y=0.001+x	y=0.027+0.96x	y=0.012+0.99x

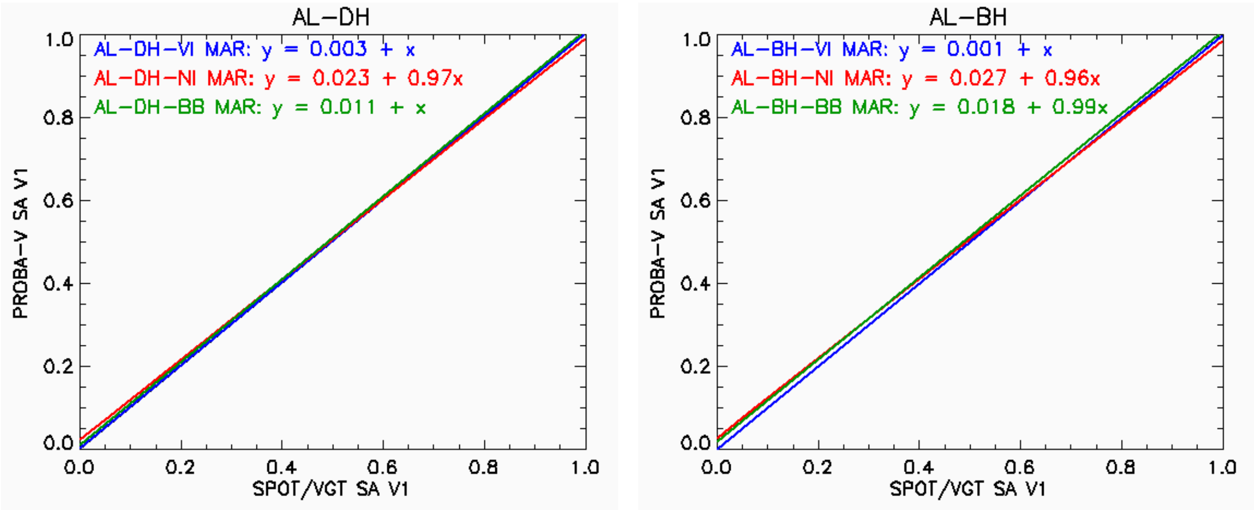


Figure 3: Major Axis Regression relationship between PROBA-V and SPOT/VGT Directional albedo (left) and Bi-hemispherical albedo (right) during December 2013 to May 2014, computed over LANDVAL network of sites.

Furthermore, the spatial autocorrelation of the products is analyzed over surfaces that are known to be homogeneous and stable. For this purpose, two spatial indicators were used: the coefficient of spatial variation (CV) and the Moran's Index (MI). The CV is defined by the ratio of the standard deviation to the mean. It is a useful measure of the relative spread in the data and provides an estimate of overall variability that is independent of spatial scale (Román et al., 2009). The MI is a measure of spatial autocorrelation (Moran, 1948), which is close to 0 for random spatial pattern, and ranges from -1 to 1 indicating negative or positive spatial autocorrelation.

Temporal Consistency

The realism of the temporal variations and the precision of the products are assessed over the 725-site LANDVAL network (see section 3.4) plus 17 additional sites with availability of ground measurements (see section 3.3). The temporal variations of the product under study are qualitatively analyzed as compared to reference products. 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.

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 product value from the linear estimate based on its neighbours can be used as an indication of intra-annual precision. 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.

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 section 3.4).

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 differences (bias). 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.

Accuracy Assessment

Accuracy is quantified by several metrics reporting the goodness of fit between the products and the corresponding ground measurements (

Table 11). 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).

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 section 3.3).

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 predefined levels (Table 4).

Summary of Quality Assessment Procedure

Table 7 summarizes the validation criteria used for the quality assessment of Collection 1km PROBA-V SA V1 product. This study is focused on 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 for the whole 2014 year. The accuracy assessment of PROBA-V SA V1 (and MODIS C5 for benchmarking) is performed against ground data coming from SURFRAD and EFDC stations during the whole 2014 year.

Table 7: Summary of the QA procedure

<table>
<tr><th>Quality Criteria</th><th>Product evaluated</th><th>Reference Product</th><th>Coverage</th></tr>
<tr><td rowspan="2">Completeness</td><td>PROBA-V V1</td><td>SPOT/VGT V1</td><td>Global
LANDVAL</td></tr>
<tr><td colspan="3">Global Gap size distribution (average maps, temporal variations per biome/continent).
Length of gaps (LANDVAL).</td></tr>
<tr><td rowspan="2">Spatial Consistency</td><td>PROBA-V V1</td><td>SPOT/VGT V1
MODIS C5</td><td>Global
AOIs (see3.5)</td></tr>
<tr><td colspan="3">Visual inspection global maps and sub-continental zooms (Figure 1).
Difference maps and histograms of residuals (global maps).
MI and CV over selected homogeneous areas (AOIs)</td></tr>
<tr><td rowspan="2">Temporal Consistency</td><td>PROBA-V V1</td><td>SPOT/VGT V1
MODIS C5
Ground data</td><td>LANDVAL
Ground reference stations (see 3.3)</td></tr>
<tr><td colspan="3">Qualitative inspection of temporal variations and cross-correlation values (*)
Histograms of the cross-correlation per biomes</td></tr>
<tr><td rowspan="2">Intra-annual Precision (smoothness)</td><td>PROBA-V V1</td><td>SPOT/VGT V1
MODIS C5</td><td>LANDVAL</td></tr>
<tr><td colspan="3">Histograms of the smoothness</td></tr>
<tr><td rowspan="2">Overall Spatio-Temporal Consistency (Discrepancies)</td><td>PROBA-V V1</td><td>SPOT/VGT V1
MODIS C5</td><td>LANDVAL</td></tr>
<tr><td colspan="3">Scatter-plots (R, RMSD, Bias, Scattering, MAR, % uncertainty levels) per biomes & Regions.
Box-plots of uncertainty metrics (Bias and RMSD) per product value.
PDFs of retrievals & histograms of residuals per biome and region.</td></tr>
<tr><td rowspan="2">Accuracy Assessment (Error)</td><td>PROBA-V V1
MODISC5</td><td>Ground data</td><td>Ground reference stations (see3.3)</td></tr>
<tr><td colspan="3">Scatter-plots (R, RMSD, Bias, Scattering. MAR, % uncertainty levels)</td></tr>
</table>

(*)The cross-correlation between PROBA-V and SPOT/VGT ($\rho_{PBVvsVGT}$), PROBA-V and MODIS C5 ($\rho_{PBVvsMOD}$), and SPOT/VGT and MODIS C5 ($\rho_{VGTvsMOD}$) was computed during the overlap period between all of them (Dec'13-May'14).

3.2 SATELLITE PRODUCTS

In this section, the main features of the Surface Albedo products investigated in this work are described. A summary with their main characteristics can be found in Table 8.

Table 8: Characteristics of the global remote sensing surface albedo products under study. GSD stands for "Ground Sampling distance". (*) Between brackets the last day of the compositing period regarding the product date is shown.

Product	Sensor	GSD	Frequency	Composite Period(*)	Coverage (projection)	Reference
EC / CGLSV1	1) VEGETATION/SPOT 2) PROBA-V	1 km	10-days	30-days (+12)	Global (Plate Carrée)	[CGLOPS1_ATBD_SA1km-V1]
NASA / MCD43A4 C5	MODIS/TERRA+AQUA	500 m	8-days	16-days (+16)	Global (Sinusoidal)	Schaaf et al., (2002)

In order to compare the products, a similar spatial support area and temporal support period must be defined. MODIS C5 products were re-sampled over *Plate Carrée* projection at 1-km spatial sampling grid (i.e., PROBA-V and SPOT/VGT projection and GSD). Furthermore, a common temporal support period should be considered in order to quantitative compare the products. The 10-days temporal frequency of PROBA-V and SPOT/VGT was selected.

Even if a 1km MODIS C5 product exist (MCD43B4), we originally used the 500m product due to its better quality (personal recommendation from C. Schaaf, Boston University)

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.

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**)
MODIS C5	**Ancillary bits 04-07**: Shallow ocean, ocean and lake shorelines, shallow inland water, ephemeral water, deep inland water, moderate or continental ocean, Deep ocean. **Band Quality bits 00-03**: Mixed 50% or less full inversions and 25 % or less fill values (value 2), All magnitude inversions or 50% or less fill values (value 3), 75% or more fill values (value 4)

3.2.1 Evaluated dataset: PROBA-V SA Version 1.5 products.

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.

The quality assessment is performed on PROBA-V SA Collection 1km V1.5 products covering the whole globe every 10 days from the dekad of 2013.11.23 to the dekad of 2014.12.13. 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 [CGLOPS1_PUM_SA1km-V1].

3.2.2 Reference products

3.2.2.1 SPOT/VGT SA Version 1.5 Product

The SPOT/VGT SA V1.5 products used as reference in the current exercise (Version 1.5) were generated with Collection 3 of SPOT/VGT input data. They cover the overlap period between PROBA-V and SPOT/VGT (from the dekad 2013.12.03 to the dekad 2014.05.13). They are calculated using the same algorithm as the evaluated PROBA-V SA V1.5 products (§ 3.2.1 above), 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. 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).

A validation exercise was performed on the SPOT/VGT albedo V1.4 products [GIOGL1_VR_SA1km-V1]. These products were retrieved from SPOT/VGT Collection 2 input data with incorrect implementation of the sun-Earth distance. It was 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.

3.2.2.2 MODIS/Terra+AquaSurface Albedo Collection 5

The MODIS BRDF/Albedo (MCD43A3) Collection 005, available since 2000 from https://lpdaac.usgs.gov, provides 500-meters reflectance data describing both directional hemispherical reflectance (black-sky albedo) at local solar noon and bi-hemispherical reflectance (white-sky albedo) for MODIS bands 1-7 as well as for three broad-bands (visible: 0.3-0.7µm, NIR: 0.7-5.0µm, and Total: 0.3-5.0µm). The MCD43A3 albedo quantities are provided as a gridded product in the sinusoidal projection, produced every 8 days with a synthesis period of 16 days. Both Terra and Aqua data are used in the generation of this product (MODIS orbital double repeat cycle). The daily product weights the data as a function of quality, observation coverage and temporal distance from the day of interest. 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 BRDF-corrected nadir reflectance product provides a nadir-view reflectance at solar local noon in all seven MODIS bands. The detailed retrieval algorithm, including the atmospheric correction, is described in Schaaf et al., 2011, 2002.

The package MCD43, including the BRDF, albedo, and nadir surface reflectance, of MODIS C5 products has attained 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).

3.2.3 Differences in the retrieval methodology

All the satellite albedo products investigated relies on a similar approach based on the use of kernel-driven BRDF models for retrieving the albedo quantities. However, the following main differences should be considered.

Atmospheric correction: Each satellite processing chain uses its own particular method for clouds/shadow screening and atmospheric correction according to the spatial, spectral and directional capabilities of each instrument. Note that the high spectral resolution of the MODIS sensor is better for cloud detection and characterization of the atmosphere. Moreover, the higher spatial resolution of MODIS is better for detection of small clouds. MODIS uses its own aerosol optical thickness product to retrieve surface reflectance for each observation, whereas SPOT/VGT and PROBA-V uses a monthly aerosol optical thickness value from the MODIS product. Larger discrepancies are then expected in situations with large aerosol conditions.

BRDF model: SPOT/VGT and PROBA-V uses the Roujean et al., (1992) model, whereas MODIS uses the Ross_Thick kernel (Roujean et al., 1992)for volumetric scattering and the Li Sparse-Reciprocal kernel for geometrical scattering (Lucht et al., 2000). Discrepancies between different albedo estimates are partly due to the different BRDF model used as shown in Carrer et al., (2010), which should applies also to TOC normalized reflectances. Moreover, the performance of the BRDF model for good clear-sky observations also depends on the number of available looks during the synthesis period and the angular distribution of the sampling. Large BRDF uncertainties are associated to snow targets, for which none of these parametric BRDF models were well suited (Maignan et al., 2004).

Angular sampling: One of the main differences in the albedo retrieval of the products under study comes from the different angular sampling used for the BRDF characterization. MODIS, SPOT/VGT and PROBA-V are wide-FOV sensors in polar orbiting platform that allows observing the surface under different sun-view configurations during consecutive tracks. The impact of having a better angular sampling and distribution of looks for the BRDF inversion should be more important over heterogeneous surfaces (higher anisotropy) like boreal forest than over homogeneous sites (lower anisotropy) like herbaceous or dense forests.

Compositing period: The compositing period of the different products is 16-days for MODIS and 30-days for PROBA-V and SPOT/VGT SA V1 products with concomitant dates between both. The different compositing period could play an important role mainly in rapid surface albedo variations such as snow falling events. Monthly MODIS products have been generated to minimize the impact of the different compositing period in the quantitative inter-comparison with PROBA-V products.

Input spectral data: Table 10 summarizes the four optical spectral bands of the VEGETATION and PROBA-V sensors, and its equivalent MODIS bands. SPOT/VGT and PROBA-V channels provide very similar spectral characteristics in Blue, Red and NIR bands. Conversely, SWIR band show larger variations since PROBA-V spectral response is narrower than SPOT-VGT and the centre presents a large difference. MODIS bands present similar centre in Red, and some differences in Blue, NIR and SWIR. Note also that MODIS channels are narrower than SPOT/VGT or PROBA-V, which could introduce discrepancies in regions with high absorption features like in the Red band.

Table 10: Spectral characteristics of VEGETATION, PROBA-V and MODIS sensors.

	VEGETATION			PROBA-V			MODIS		
	Acronym	Centre (nm)	Width (nm)	Acronym	Centre (nm)	Width (nm)	Acronym	Centre (nm)	Width (nm)
Blue	B0	450	40	B0	470	46	Band3	489	20
Red	B2	645	70	B2	650	80	Band1	645	50
NIR	B3	835	110	B3	831.5	123	Band2	858.5	35
SWIR	SWIR	1665	170	SWIR	1610	80	Band6	1639	24

Broadband conversion: The broadband albedos of each satellite product are estimated from their respective sensor spectral bands, which differs in number and spectral response. Moreover, the broadband albedos are defined using slightly different spectral regions. Three broadband albedos are defined in both SA V1 products:

- Over the visible range [0.4µm – 0.7µm]
- Over the near-infrared range [0.7µm – 4µm]
- Over the total shortwave band [0.3µm – 4µm]

On the other hand, MODIS C5 surface albedo products are defined using the following respective three broad bands: 0.3-0.7µm, 0.7-5.0µm, and 0.3-5.0µm.

3.3 IN-SITU REFERENCE PRODUCTS

The accuracy of PROBA-V SA V1.5 Albedo products was estimated against ground reference data coming from SURFRAD (http://www.esrl.noaa.gov/gmd/grad/surfrad/sitepage.html) and the European Fluxes Database Cluster (EFDC) (http://gaia.agraria.unitus.it/home/log-in/) stations. The accuracy of MODIS C5 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.

For SURFRAD data, the comparison was carried out using monthly averages of field measurements at noon over the similar compositing period of the satellite product. For benchmarking with MODIS products, coincident observations during the monthly periods were averaged. For EFDC, the ground data was made available daily. 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 11: SURFRAD and EFDC sites providing field albedo measurements

Site	Country	Network	Land Cover	Lat (deg)	Lon (deg)	Diffuse Method
Bondville	USA	SURFRAD	Grassland	40.05	-88.37	Direct
Table Mountain Boulder	USA	SURFRAD	Grassland	40.13	-105.24	Direct
Desert Rock	USA	SURFRAD	Desert	36.63	-116.02	Direct
Fort Peck	USA	SURFRAD	Grassland	48.32	-105.1	Direct
Sioux Falls	USA	SURFRAD	Grassland	43.73	-96.62	Direct
BilyKriz 1	Czech Rep.	EFDC	NLF	49.50	18.54	Direct
Oberbärenburg	Germany	EFDC	NLF	50.78	13.72	Indirect
Cortes de Pallas	Spain	EFDC	Shrublands	39.22	-0.90	Direct
Majadas del Tietar	Spain	EFDC	Savanna	39.94	-5.77	Direct
Puechabon	France	EFDC	EBF	43.74	3.60	Direct
Guyaflux	French Guiana	EFDC	EBF	5.28	-52.92	Direct
Collelongo	Italy	EFDC	DBF	41.85	13.59	Direct
Brody	Poland	EFDC	Crop	52.43	16.30	Direct
Zackenberg Heath	Denmark	EFDC	Grassland	74.47	-20.55	Indirect
Monte Bondone	Italy	EFDC	Grassland	46.02	11.05	Direct
Tharandt	Germany	EFDC	NLF	50.96	13.57	Direct
Tuczno	Poland	EFDC	DBF	53.19	16.10	Direct

SURFRAD stations and some EFDC stations provide the diffuse down-welling shortwave radiation information (see 'Diffuse method' = 'Direct' in Table 11). For the stations where diffuse radiation information was not provided (see 'Diffuse method' = 'Indirect' in Table 11), the estimation of the diffuse fraction involved two steps. The first step was the extract of the aerosol optical depth values for each site and each calendar date using the measurements from the nearest AERONET station. In the second step, the radiative transfer model MODTRAN was used for modelling the diffuse irradiance using as input the AERONET aerosol optical depth values.

Table 11 shows the 17 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 reported in ANNEX I.

3.4 LANDVAL NETWORK OF SITES

In order to identify a reference network of sites for inter-comparison, a global land validation network (LANDVAL) was specifically defined for surface reflectance products. At first, 2186 potential sites coming from SAVS 1.0 (Surface Albedo Validation Sites) network (Loew et al., 2016) were analyzed (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. SAVS 1.0 is a static database of potential validation sites coming from existing networks (FLUXNET, BSRN, AERONET, BELMANIP2.1, DIRECT, CEOS LandNet, EOS core sites, SURFRAD, LTER, SAFARI2000, ALBEDOVAL-1), correlated with various ancillary data in respect to their spatial and temporal homogeneity, to fully characterize the sites for land product validation. Statistical measurements are provided enabling the user to easily filter the database using their own criteria. It is a powerful tool to provide a traceable approach to characterize potential sites for EO product validation. The selection criteria that have been chosen for each SAVS 1.0 site are showed in Table 12.

Table 12: 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

521 sites, among the 2186, achieved the above criteria of selection, from which 256 are coming from BELMANIP2.1 (Baret et al., 2006). An oversampling of this network over Europe and North of America continental regions, as well as for Cultivated and Herbaceous biome types, was observed. So the second step of the definition of LANDVAL was to include additional sites over under-sampled biome types and regions.

Furthermore, 20 sites ('*calibration sites*') in the Sahara desert and Arabia desert were added 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. Furthermore, 184 sites under similar criteria in terms of spatial homogeneity and topography were included in order to cover under sampled regions (Asia, Africa, Oceania) and biome types (Shrub, deciduous broadleaf forest (DBF), needleleaf forest (NLF)). 26 of those 184 sites come from existing networks (e.g. ImagineS (http://fp7-imagines.eu/), AsiaFlux , NARMA or OzFlux). 158 of those 184 additional homogeneous sites have been selected from the Geo-Wiki platform (http://www.geo-wiki.org/). Finally, the network is composed with a total of 725 sites (Figure 4, Table 13).

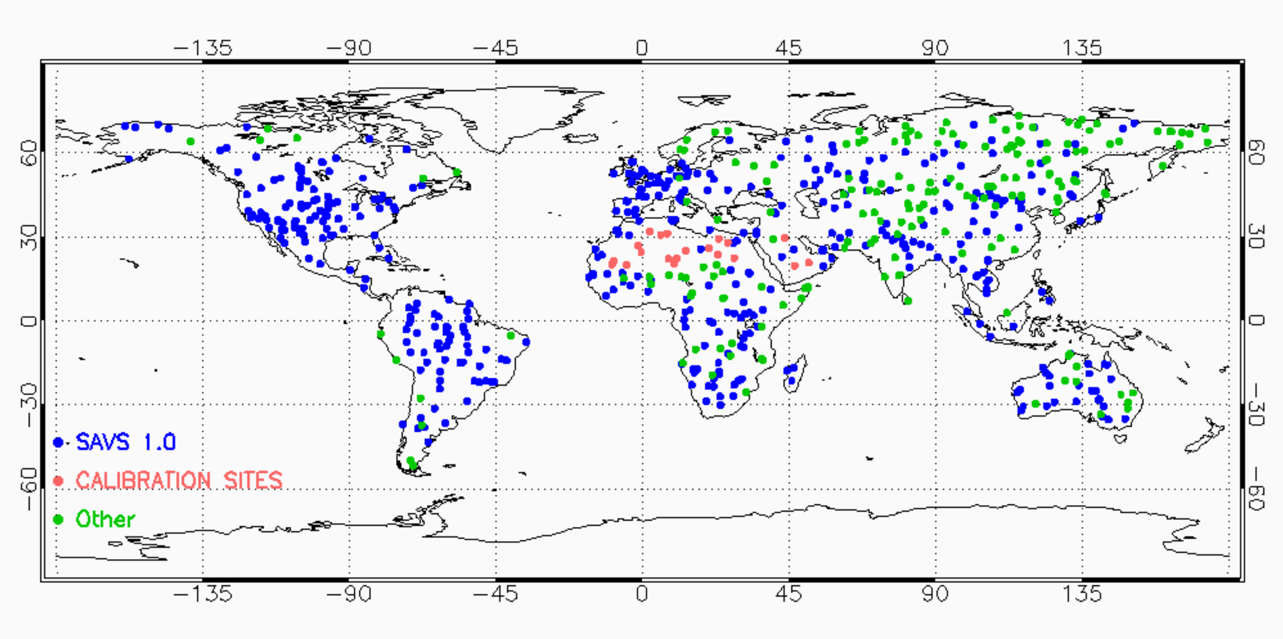


Figure 4: Global distribution of the selected LANDVAL sites.

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 5). 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). An additional class of 'Snow' was analyzed. To identify snow pixels, the surface albedo retrievals in visible domain were used, and pixels with retrievals greater than 0.5 were classified as snow.

Table 13: Number of reference sites coming from SAVS 1.0, Desert Calibration Sites and additional sites from existing networks and Geo-Wiki.

Network	# of sites
SAVS 1.0	521 (including 256 BELMANIP2.1)
Calibration Sites	20
Additional sites (from existing networks)	26
Additional sites (Geo-Wiki)	158
Total	**725**

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 5).

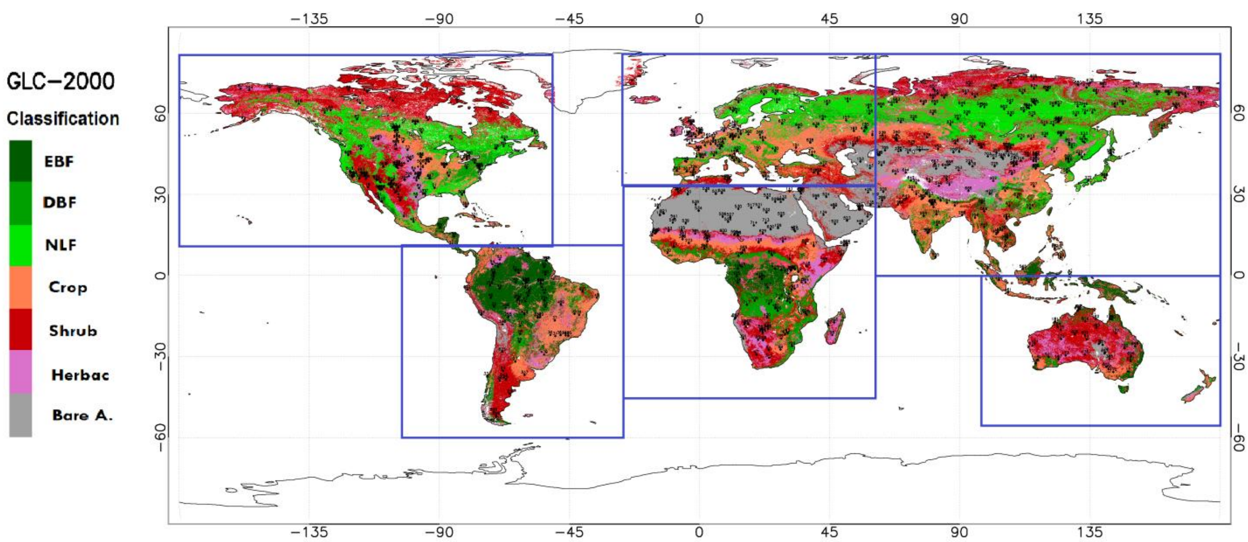


Figure 5: Location of the LANDVAL sites over an aggregated land cover (GLC-2000) map. Blue squares correspond to the six continental regions.

Finally, Figure 6 shows the evaluation of the sampling per biome type and continental region for the LANDVAL network and the global distribution. Less than 10% of differences were found for all biome type and region between the LANDVAL network and the global distribution. Per biome type, only some oversampling of LANDVAL network was found for cultivated areas. Per continental region, slight under-sampling of LANDVAL was found over Asia whereas the opposite trend was found over North of America and Europe. Note that most of the additional sites were added over the Asian region, but greater difficulties were found here to select sites under optimal criteria of spatial homogeneity and topography.

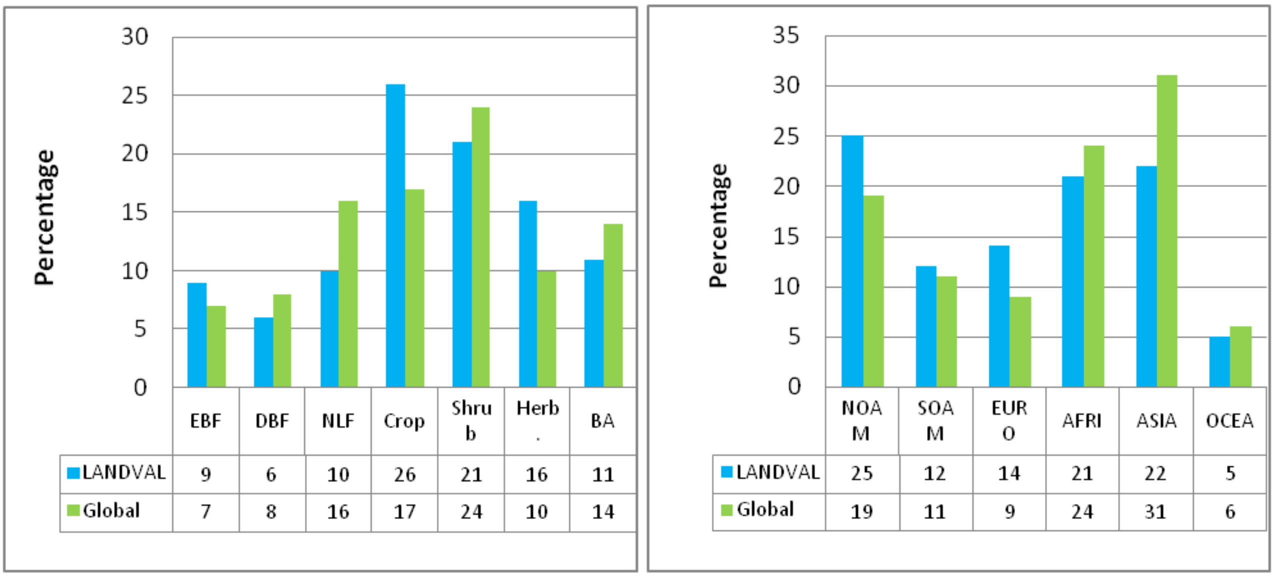
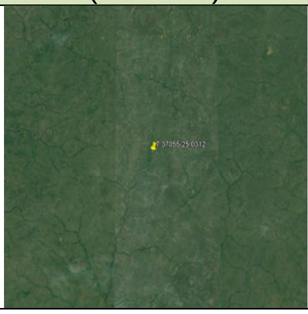
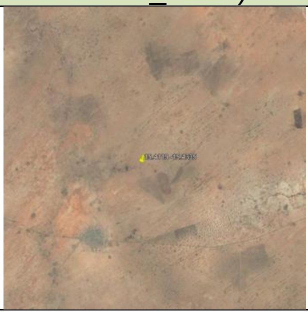


Figure 6: Distribution of the percentage LANDVAL network of sites and pixels of global GLC-2000 map per aggregated main biome type (Left) and continental region (Right).

3.5 AREAS OF INTEREST FOR SPATIAL CORRELATION ASSESSMENT

The spatial autocorrelation analysis was performed over 6 LANDVAL sites that are known to be homogeneous and stable up to ~50x50 km^2 (Table 14). One site for each main biome type was selected to represent the different land covers except for cultivated where lower spatial correlation is expected.

Table 14: Central coordinates of the 6 selected LANDVAL sites for the Spatial Correlation analysis and Google Earth View of 50kmx50km.

AOI#1 EBF	AOI#2 DBF	AOI#3 NLF
LANDVAL#55 (BELMANIP_00050)	LANDVAL#715 (Mbomou)	LANDVAL#244 (BELMANIP_00410)
		
Lat=17.594º Lon=-89.7827º	Lat=7.37055º Lon=25.0312º	Lat=61.7218º Lon=113.89º
AOI#4 Shrublands	**AOI#5 Herbaceous**	**AOI#6 Bare Areas**
LANDVAL#346 (DIRECT_0087 -Dahra_North)	LANDVAL#172 (BELMANIP_00284)	LADNVAL#540 (Mauritania#1 Calibration Site)
		
Lat=15.4119º Lot=-15.4335º	Lat=-23.6509º Lon=124.98º	Lat=19.9º Lon=-9.3º

4 RESULTS

4.1 PRODUCT CONTENT &VISUAL INSPECTION OF GLOBAL MAPS

Global maps of the PROBA-V black-sky and white-sky albedos for the three spectral ranges (BB, NI, VI) and their respective ancillary layers (ERR, NMOD, QFLAG) have been checked during the period under study (from November 2013 to December 2014) at 1/16 of its original resolution. All the maps during the whole 2014 year can be found into the Digital Annex.

4.1.1 SA product values

The physical values of black-sky (white-sky) albedos for visible, near infrared and shortwave spectral domains are given in AL-DH-VI, AL-DH-NI and AL-DH-BB (AL-BH-VI, AL-BH-NI and AL-BH-BB) layers respectively.Figure 7, Figure 8 and Figure 9 show two examples of black-sky albedos for each spectral domain (visible, NIR and shortwave).

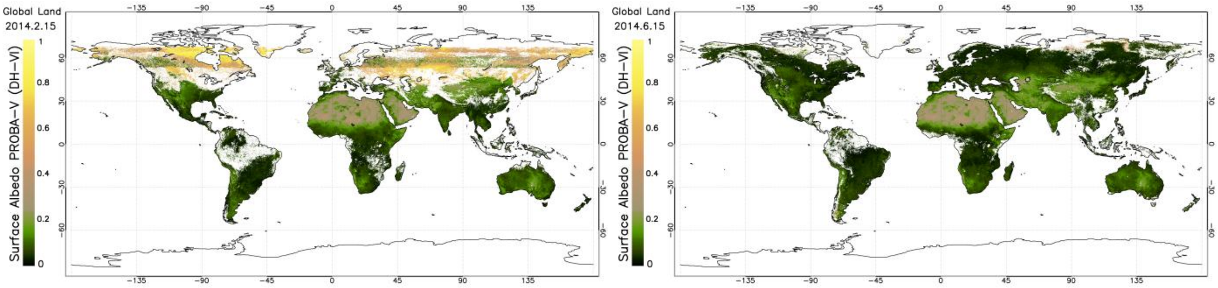


Figure 7: PROBA-V AL-DH-VI global maps for mid of January and mid of June, 2014.

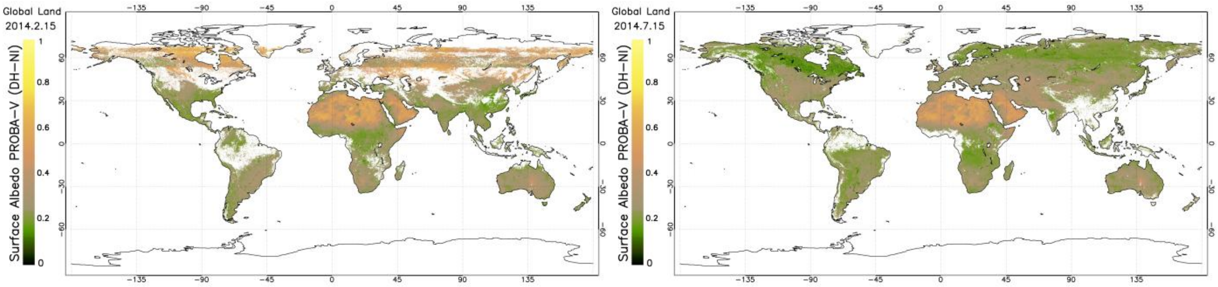


Figure 8: PROBA-V AL-DH-NI global maps for mid of February and mid of July, 2014.

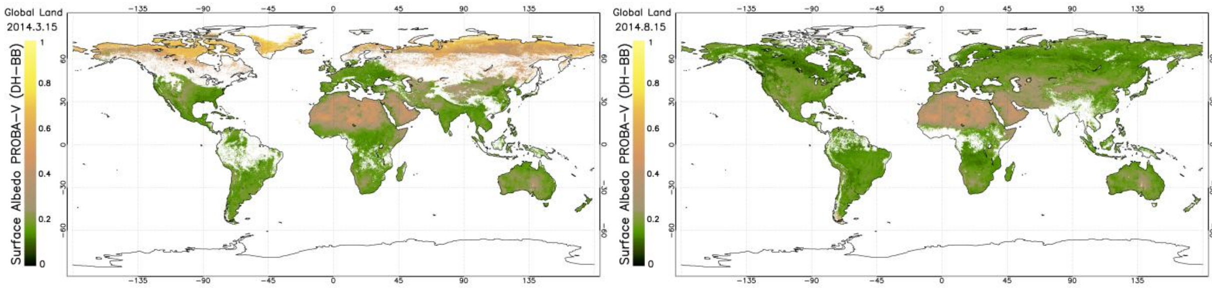


Figure 9: PROBA-V AL-DH-BB global maps for mid of March and mid of August, 2014.

Main findings of the global maps are:

- A consistent distribution of values was generally found, without finding suspicious patterns for all the dates.
- However, a sharp latitudinal transition over northern hemisphere (around ~50º) was observed during December 2013, January 2014, February 2014 and December 2014 (see global maps in Digital Annex). The same effect was observed during March 2014 around 65º. This spatial artifact was observed in black-sky and white-sky retrievals (all spectral domains) and the ancillary layers corresponding to error estimates (ERR) and number of observations (NMOD). This spatial pattern is linked to the status map of PROBA-V input data, used to identify the cloudy pixels in the SA retrieval algorithm, which presents the same pattern. 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 [product_user_manual.pdf] due to the use of Land Cover CCI map and GlobAlbedo surface albedo as ancillary information.

4.1.2 Ancillary Layers

- **ERR**

The error estimates (ERR) of black-sky (white-sky) albedos over visible band, near infrared band and total spectrum are given in AL-DH-VI-ERR, AL-DH-NI-ERR and AL-DH-BB-ERR (AL-BH-VI-ERR, AL-BH-NI-ERR and AL-BH-BB-ERR) layers respectively. Figure 10, Figure 11 and Figure 12 show two examples of global maps for each spectral range. Note that physical range of ERR oscillates between 0 and 1, and global maps are displayed with the maximum value saturated at 0.2.

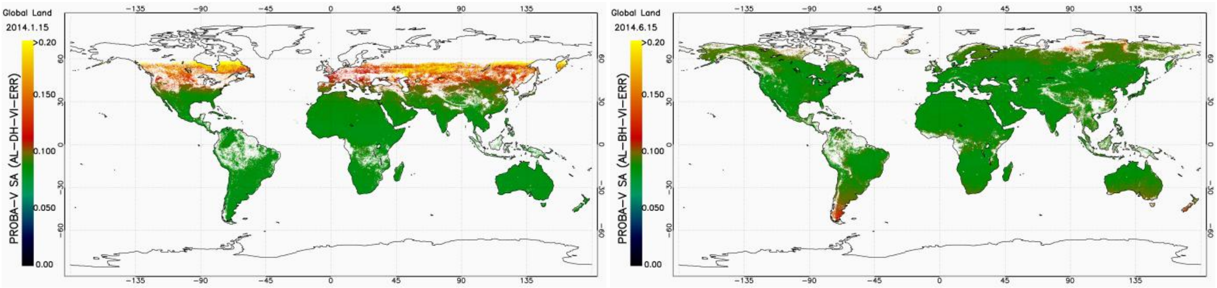


Figure 10: AL-DH-VI-ERR global maps for mid of January 2014 (left) and AL-BH-VI-ERR global map for mid of June 2014 (right).

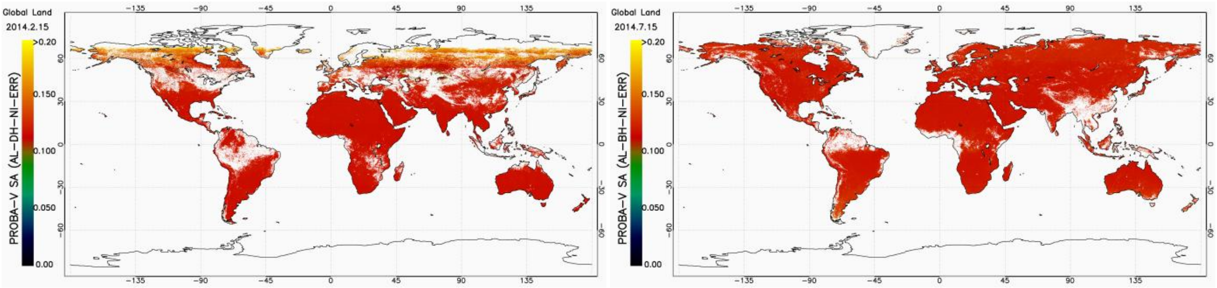


Figure 11: AL-DH-NI-ERR global maps for mid of February 2014 (left) and AL-BH-NI-ERR global map for mid of July 2014 (right).

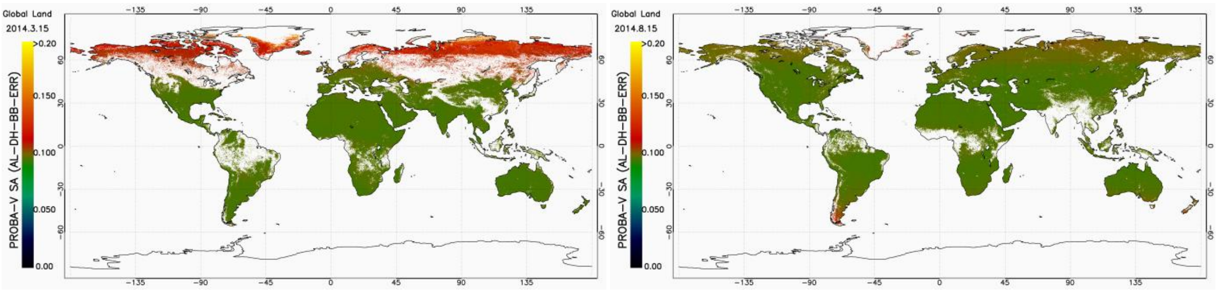


Figure 12: AL-DH-BB-ERR global maps for mid of March 2014 (left) and AL-BH-BB-ERR global map for mid of August 2014 (right).

Main conclusions are:

- For visible domain (Figure 10), typically values around 0.08 were found over the whole globe, showing low variability, except over snow areas over northern regions (latitudes from 40º), where higher errors were found (0.1-0.2).
- Similar trend was found for the shortwave (Figure 12), showing values around 0.095 around the whole globe (low variability) and higher values over northern latitudes over snow areas.
- For near infrared (Figure 11) error values are higher, typically ranging from 0.11 to 0.13, showing low variability over the whole globe.

- **NMOD**

The parameter NMOD corresponds to the number of PROBA-V input measurements used to calculate the albedo, and hence reflects the number of valid observations during the synthesis period [CGLOPS1_PUM_SA1km-V1]. Figure 13 shows the NMOD global maps during the 2014 year, with a temporal frequency of two months. The physical values of NMOD are within the range [0, 60], and maps in Figure 13 are are displayed with the maximum value at 30.

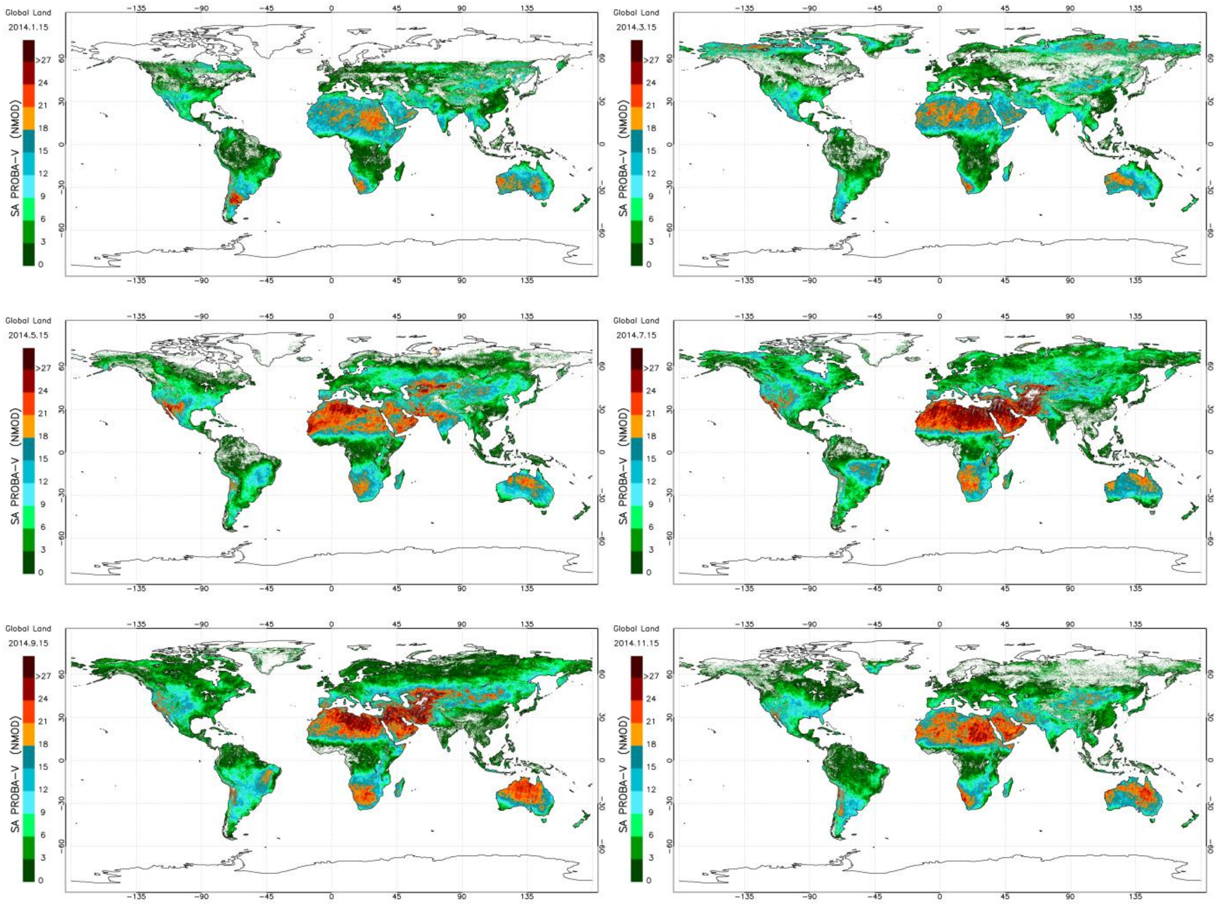


Figure 13: Global maps of NMOD layer of PROBA-V SA V1.5 products during the 2014 year.

As expected, higher values (up to 30) are located over desertic areas, characterized by lack of clouds, whereas lower values (~5 - 10) are located over equatorial areas and northern latitudes.

- **QFLAG**

The quality flag (QFLAG) is coded on 2 bytes and must be read bit per bit, except for the missing value equal to 65535. Its description is given in the table below. Bit 12 and higher ones have no meaning and are set to zero.

Table 15: Description of the QFLAG of AL-DH and AL-BH products. "XX" on bits 7, 8 and 9 means "DH" or "BH" depending on the products.

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

The principal bits of the QFLAG were analyzed and globally displayed for the period under study.

Figure 14 shows the activation of bits 1 (Land/Sea) and 2 (Snow Status) during the 2014 at three month of temporal frequency.

Main observations are:

- Consistent activation of bit 1 (Land/Sea) was found. However, large inland water bodies (see Victoria Lake or Caspian Sea) are classified as 'Land' according to the PROBA-V data land-sea mask.
- Regarding the activation of bit 2 (Snow Status), consistent activation of this bit was found, but some unrealistic snow pixels are displayed over equatorial areas. That result from limitation in the PROBA-V cloud masking [probav_cloudmask_validation_v1.0.pdf]. However, most of PROBA-V SA V1.5 pixels flagged as 'snow' by bit 2 of QFLAG over equatorial areas does not provide valid retrievals.

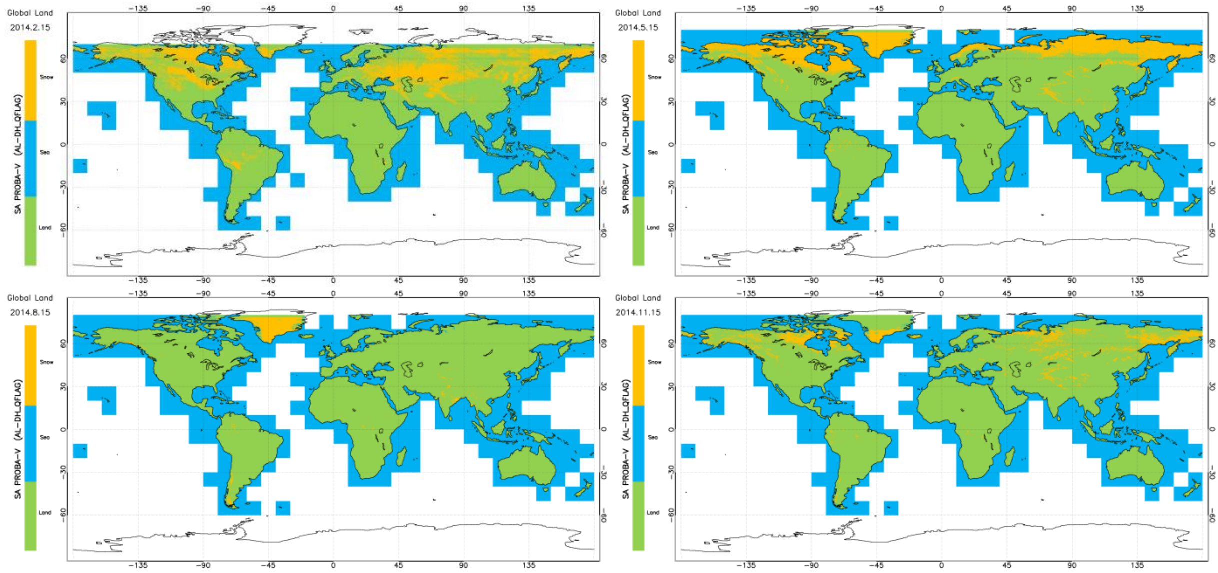


Figure 14: Global maps of the activation of bits 1 (Land/Sea) and 2 (Snow Status) of the PROBA-V AL-DH QFLAG for mid of February, May, August and November of 2014. Yellow: Snow land pixels. Blue: sea pixels. Green: Land snow-clear pixels. White pixels correspond to filled values.

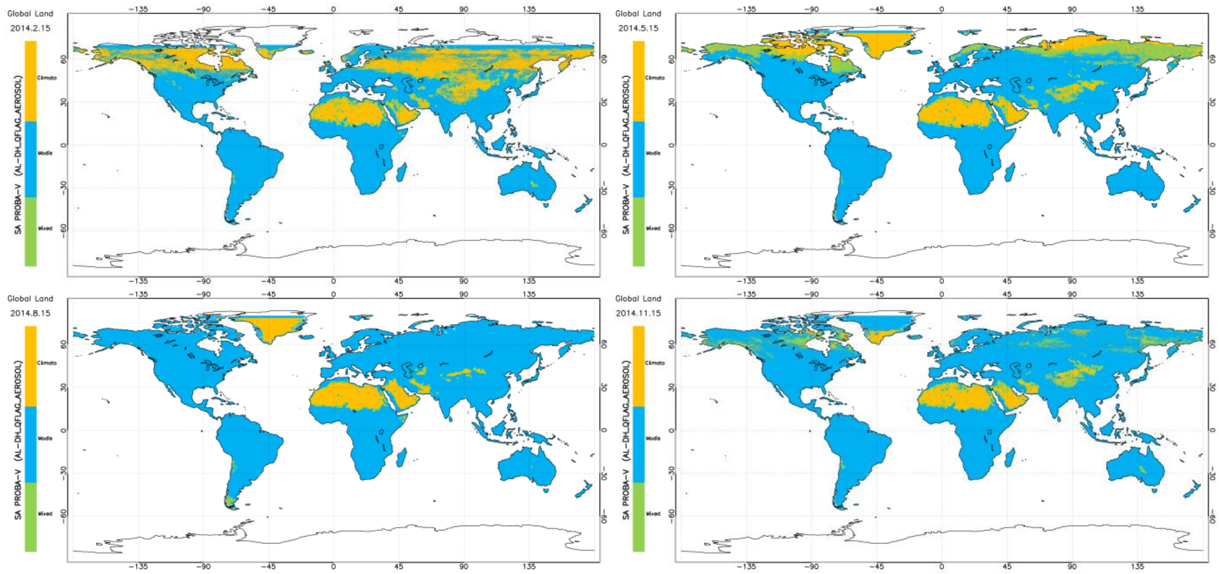


Figure 15: Global maps of the activation of bits 4 (Aerosol status) and 5 (Aerosol source) of the PROBA-V AL-DH QFLAG for mid of February, May, August and November of 2014. Yellow: Status=Pure, Source=Latitudinal gradient. Blue: Status=Pure, Source=MODIS. Green: Status=Mixed. White pixels correspond to filled values.

Figure 15 displays some examples of the behavior of the Aerosol information, related to the bits 4 (Aerosol status) and 5 (Aerosol source). Yellow and Blue colors represent pixels under 'Pure' aerosol sources from 'MODIS' and 'Climato', respectively. Green pixels represent pixels where 'Mixed' aerosol information was used for the atmospheric correction.

In general, the main source of the Aerosol information to retrieve the SA is the 'MODIS' product. Only over desertic areas, northern latitudes and some regions mainly located in Asia, the source of the Aerosol information is 'Mixed' or 'Latitudinal gradient'.

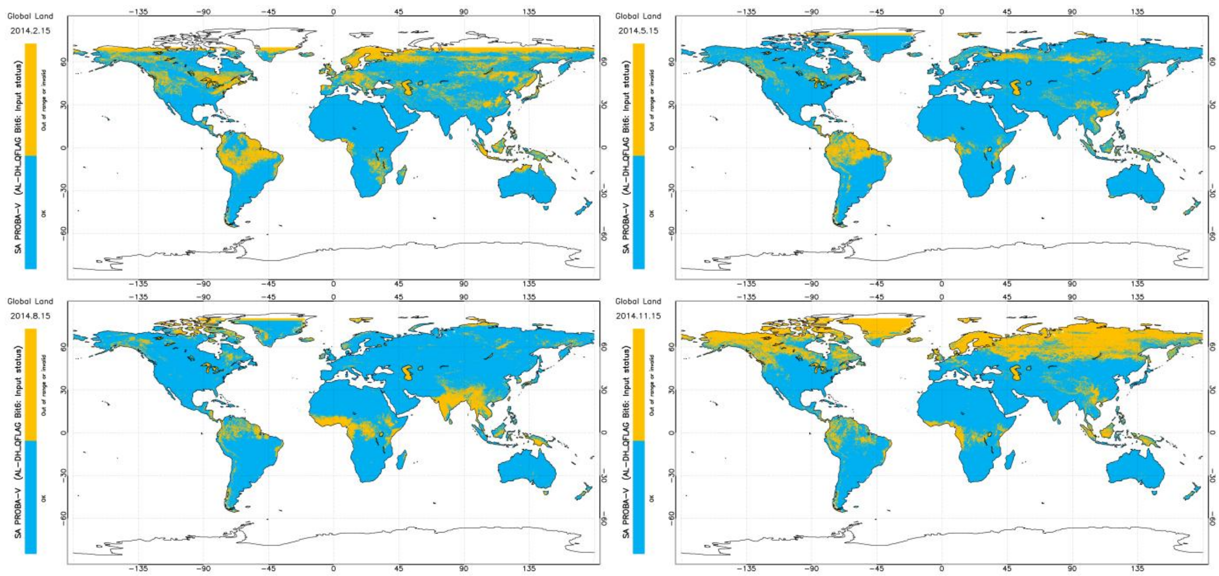


Figure 16: Global maps of the activation of bit 6 (Input status) of the PROBA-V AL-DH QFLAG for February, May, August and November of 2014. Yellow: Input status "out of range or invalid". Blue: Input status "OK". White pixels correspond to filled values.

The activation of the input status (bit 6) was checked and displayed in Figure 16. Blue color represents input status 'OK' (bit 6 = 0) and yellow color input status 'out of range or invalid' (bit 6 = 1).

As showed in Figure 16:

- Pixels showing input status 'OK' were generally found over the whole globe. Pixels showing input status 'out of range or invalid' were mainly located over equatorial areas, mainly affected by cloud contamination, and northern latitudes (i.e. snow pixels).
- Bit 6 of QFLAG classifies the inland water pixels as 'out of range or invalid'. As these water bodies are classified as "land" and not "water" (Bit 1 and Figure 14), the SA processing is applied over these pixels. However, as the BRDF model was not designed to reproduce the water BRDF, its inversion fails and the resulting BRDF coefficients, input of the SA calculation, are invalid.

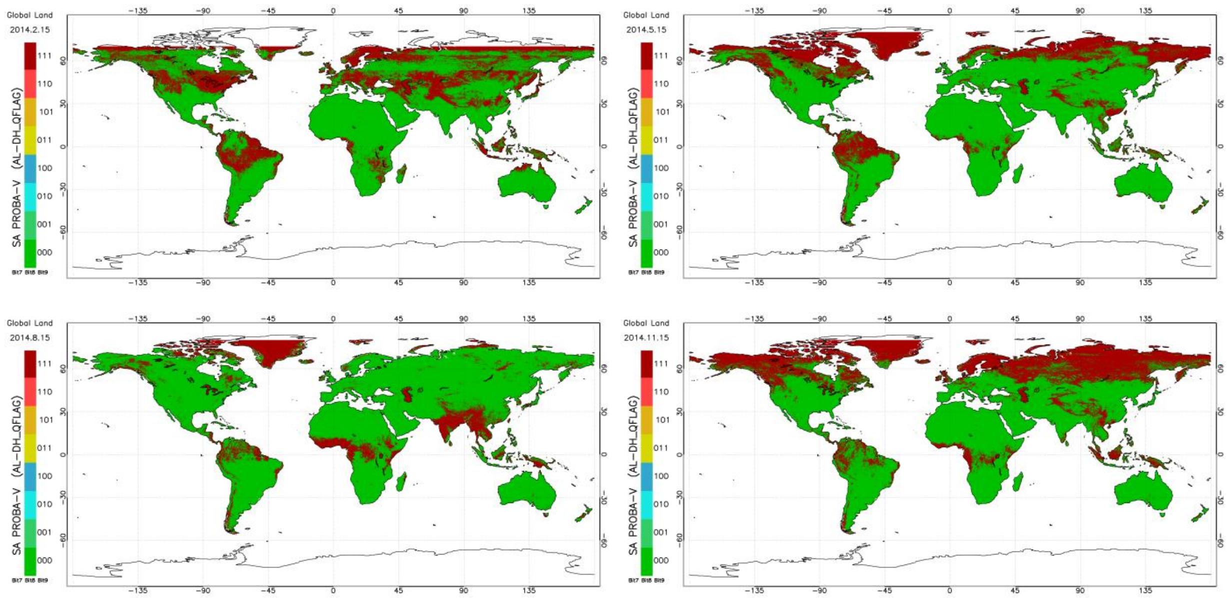


Figure 17: Global maps of the activation of bits 7, 8 and 9 of the AL-DH QFLAG, corresponding to AL-DH-VI, AL-DH-NI and AL-DH-BB status, for mid of February, May, August and November of 2014. Bits set to '0' correspond to status 'OK' and set to '1' to 'out of range or invalid'.

Bits 7, 8 and 9 corresponding to the AL-DH and AL-BH status in visible, near infrared and total spectrum respectively were also checked. Figure 17 displays the status of AL-DH-VI, AL-DH-NI and AL-DH-BB during the 2014 at three month of temporal frequency.

Main conclusions are:

- Bits 7, 8 and 9 of the QFLAG are activated simultaneously. Only two combinations were observed: status 'OK' in all in visible, near infrared and total spectrum, or status 'out of range or invalid' in the three spectral domains.
- The activation of bits 7, 8, 9 is correlated to the activation of bit 6 (input status propagated from TOC-r). When bit 6 is activated, bits 7, 8 and 9 are also activated. However, bits 7, 8 and 9 are activated in more number of cases than bit 6, mainly observed over cloudy areas and northern regions (snow).

Finally, the activation of bits 10 and 11 was checked and displayed in Figure 18. These bits indicate the saturation status of bands B2 and B0, respectively. Bits set to '0' correspond to status 'OK' and bits set to '1' correspond to 'saturated' status.

In summary:

- Pixels showing B2 and B0 saturation status 'OK' were generally found over the whole globe. The saturation of B2 and B0 is correlated with bit 2 (snow status, see Figure 14).

- ➢ In most of cases if B2 is saturated, B0 is also saturated. The same conclusion does not apply in the opposite direction: if B0 is saturated, B2 may be 'OK'.

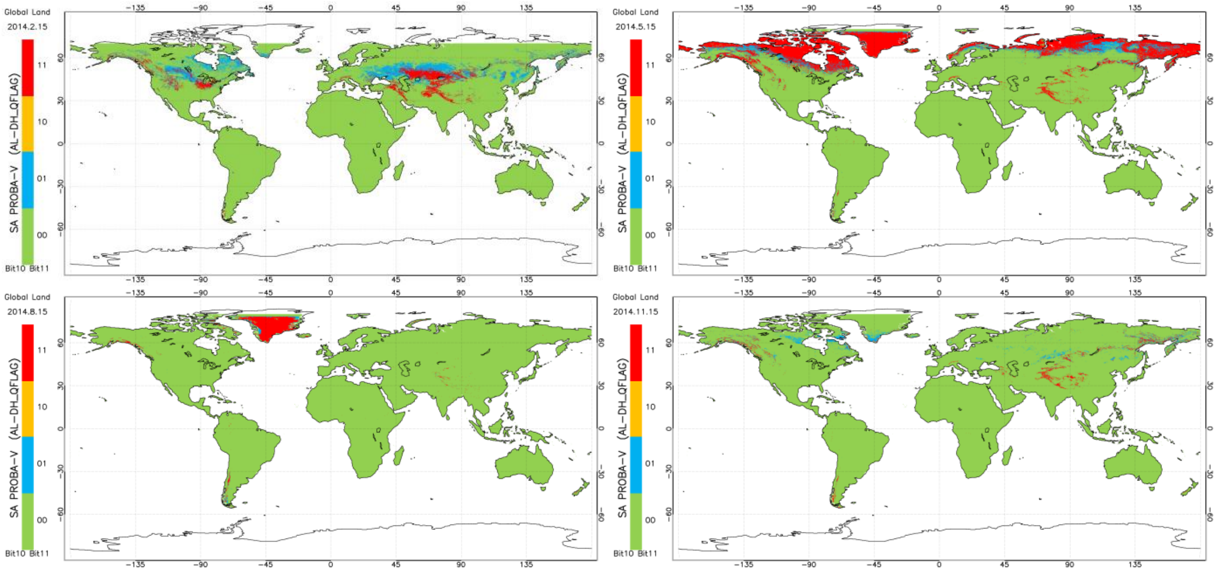


Figure 18: Global maps of the activation of bits 10 and 11 corresponding to the B2 and B0 saturation status of the PROBA-V AL-DH QFLAG for mid of February, May, August and November of 2014. Green color corresponds to status 'OK' in B2 and B0, Blue to B2 'OK' and B0 'saturated', Yellow to B2 'saturated' and B0 'OK', and red to both B2 and B0 'saturated'. White pixels correspond to filled values.

4.2 PRODUCT COMPLETENESS

Figure 19 displays a global map of the percentage of missing values during the 2014 year for the PROBA-V shortwave black-sky albedo product. The information from the Quality Flag was not considered here in the computation of gaps. Note that almost identical maps of the percentage of missing values were found for the different PROBA-V albedo products (AL-DH, AL-BH) in all spectral ranges.

The main conclusions from Figure 19 are:

- ➢ The spatio-temporal continuity of PROBA-V SA products is poor over some areas located at 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. The lack of clear-sky observations due to persistent cloud coverage is the main reason for these gaps.
- ➢ These results are consistent with the previous validation results for SA products derived from SPOT/VGT observations [GIOGL1_VR_SA1km-V1].

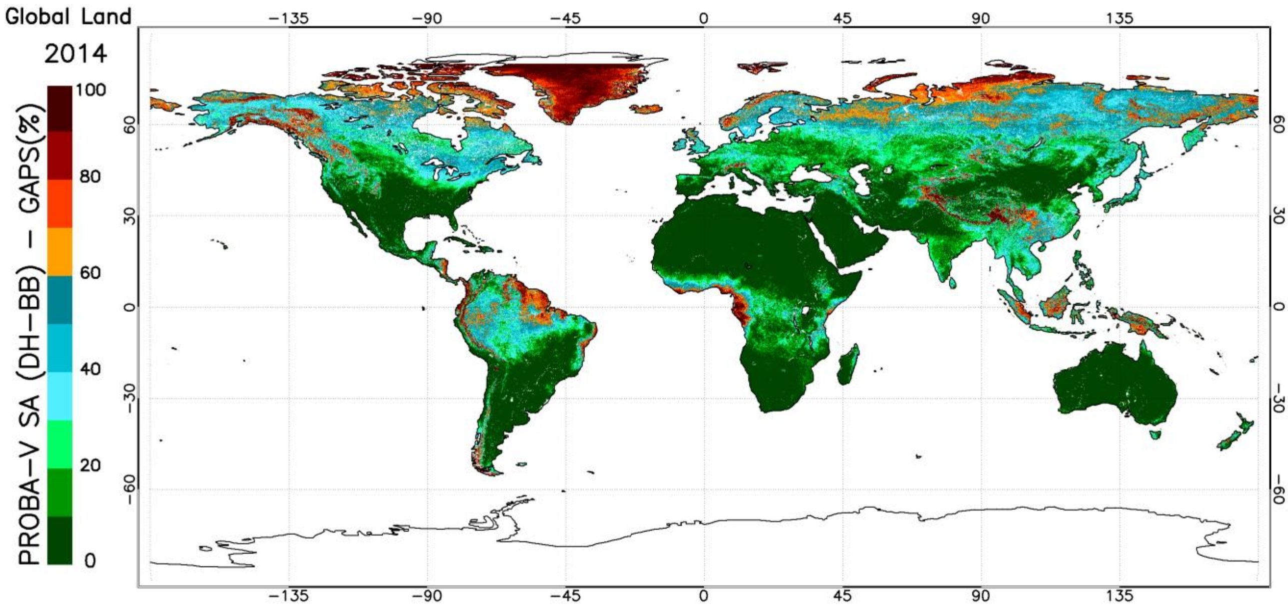


Figure 19: Percentage of missing values during the January-December 2014 period for PROBA-V AL-DH-BB product considering all land pixels.

Figure 20 shows the temporal evolution of missing values for SPOT/VGT and PROBA-V SA V1.5 products during the period from November 2013 to December 2014 for the black-sky albedo in shortwave domain. The information coming from the QFLAG was not used here. In addition, the temporal evolution of missing values per biomes and continental regions is shown in Figure 21 and Figure 22 respectively. It should be noted that almost identical results were found for all the spectral domains and white-sky albedos.

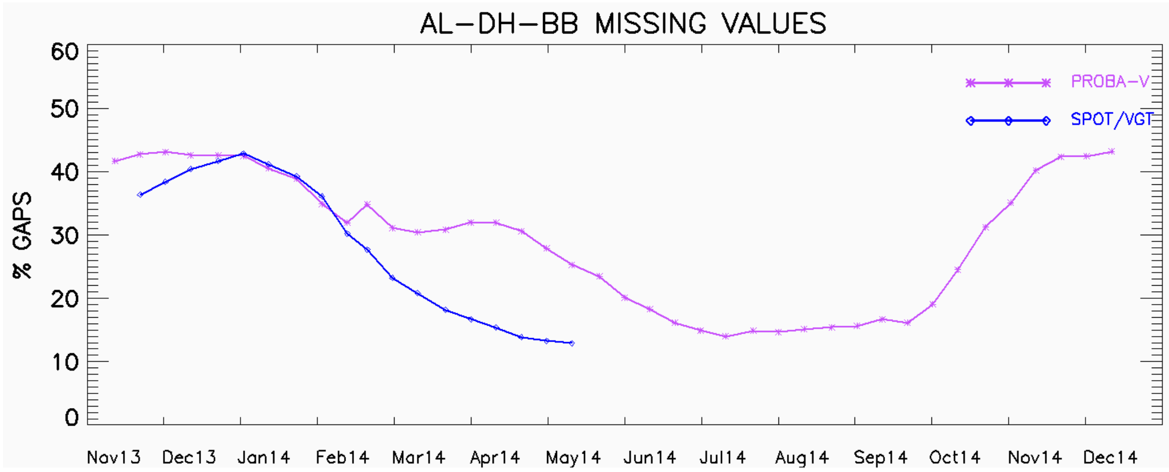


Figure 20: Temporal variations of missing values, computed over the whole globe, for SPOT/VGT (blue line) and PROBA-V (purple line) AL-DH-BB products during the period from November 2013 to December 2014.

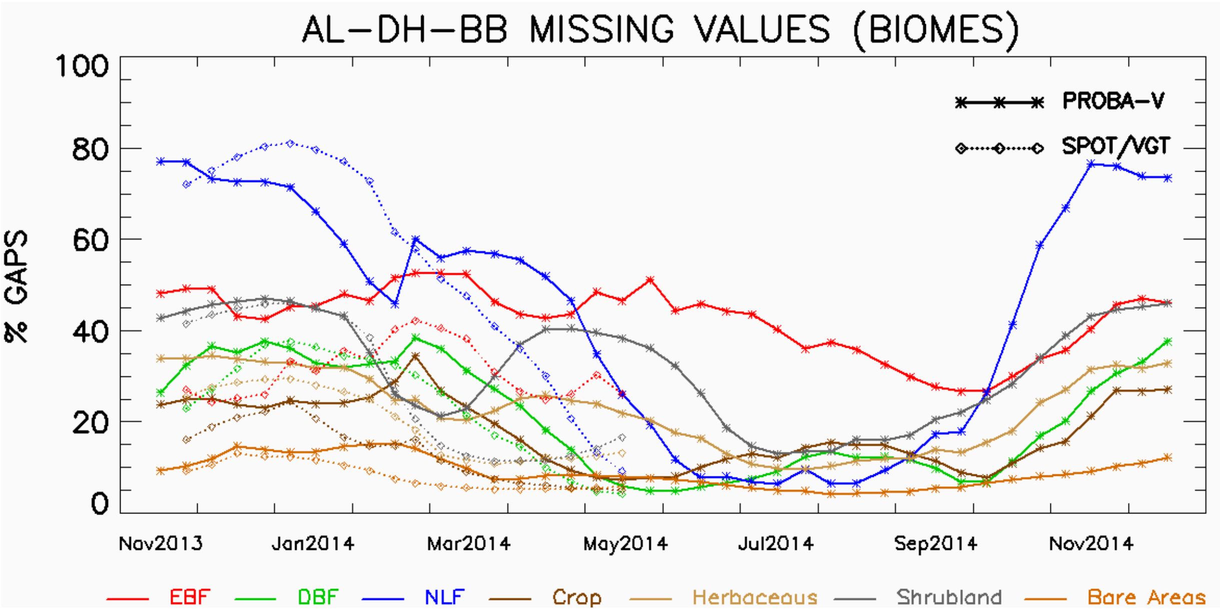


Figure 21: Temporal variations of missing values, computed over the whole globe, per biomes for Copernicus Global Land SAV1(AL-DH-BB) products during November 2013 to December 2014. SPOT/VGT (dashed line) and PROBA-V (solid line).

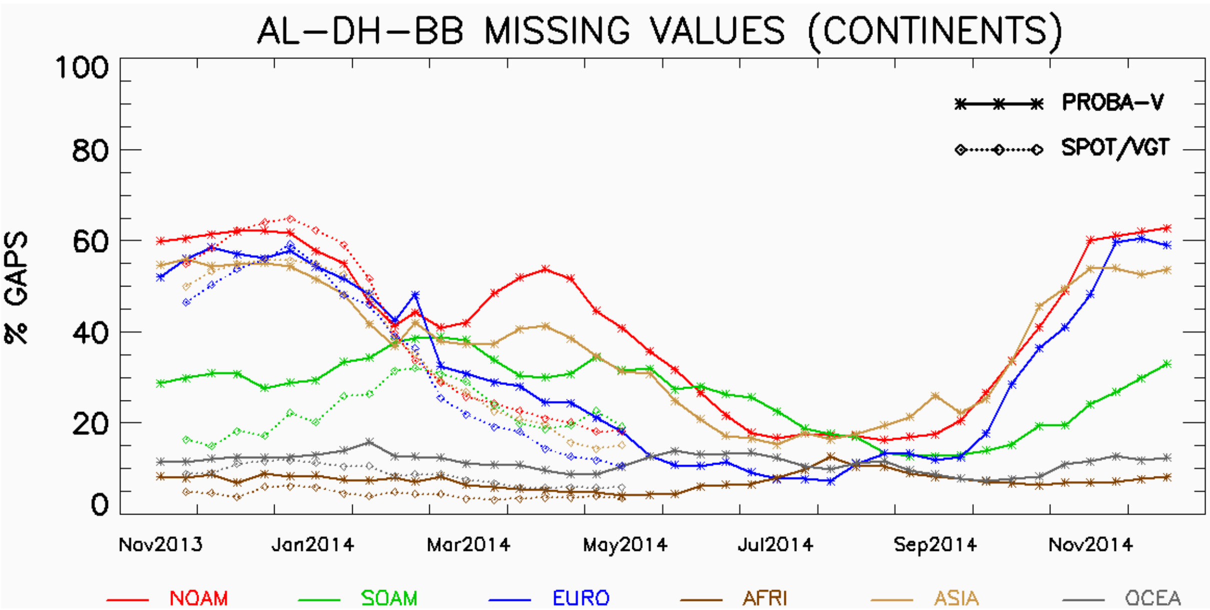


Figure 22: Temporal variations of missing values per continental regions for Copernicus Global Land SA V1.5 (AL-DH-BB) during November 2013 to December 2014. SPOT/VGT (dashed line) and PROBA-V (solid line).

Main conclusions are:

- Globally, PROBA-V shows lower fraction of valid observations than SPOT/VGT, with differences around 5% in the European winter time and up to 20% in April 2014. This can be explained by a conservative cloud detection applied on the PROBA-V input data [product_user_manual.pdf; probav_cloudmask_validation_v1]
- As expected, the highest percentage of global missing observations was found during winter period in northern hemisphere. The percentage of missing values ranges, in average, from around 15% (July and August, 2014) to 42% (January, 2014).
- Per biome type (Figure 21):
  - For Evergreen Broadleaved Forest, PROBA-V provides much larger fraction of missing data (between 40% and 50%) than SPOT/VGT (between 20% and 40%) during the overlap period.
  - For the rest of biomes, similar fraction of missing values was observed between both products (slight better percentage of good values in SPOT/VGT). The exceptions were NLF (November 2013 to mid-February of 2014) and DBF (January to mid-February of 2014), where better percentage of good values was found in PROBA-V.
- Per continental region (Figure 22):
  - Similar trend in both satellite products was observed except in NOAM.
  - In SOAM, similar trend was found but PROBA-V tends to provide much larger fraction of missing retrievals (~10%) than SPOT/VGT.
  - In NOAM, similar fraction of missing data between PROBA-V and SPOT/VGT was found during November 2013 to mid of February 2014. However, during mid of February to May 2014, much larger fraction of missing data was found in PROBA-V.
- Poor performance in terms of product completeness (i.e., large number of missing data) was found over areas (SOAM) and biomes (EBF) typically located over tropical areas during the whole period under study.

The distribution of the temporal length of the missing values was also evaluated in order to better understand the impact of the gaps for monitoring the temporal variations. The length of gaps, evaluated over LANDVAL sites, was computed during the period from December 2013 to May 2014 (SPOT/VGT, PROBA-V and MODIS, Figure 23 left), and during the 2014 year (PROBA-V and MODIS, Figure 23 right)

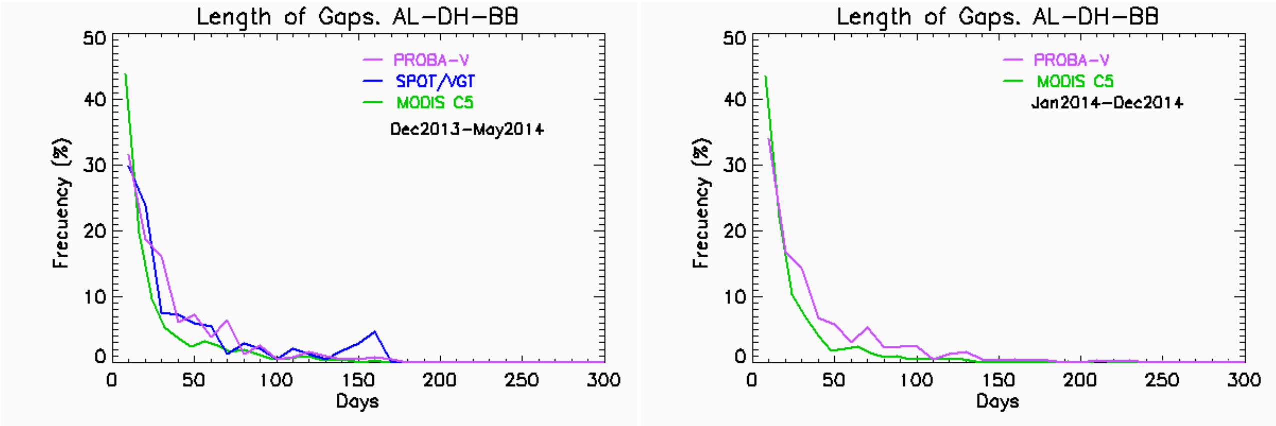


Figure 23: Distribution of the temporal length of the missing values over LANDVAL sites during the December 2013 – May 2014 period for PROBA-V V1.5, SPOT/VGT V1.5 and MODIS C5 surface albedo products (left) and during the whole 2014 year for PROBA-V V1.5 and MODIS.

The distributions of length of gaps show:

- Similar distributions were found for PROBA-V and SPOT/VGT SA V1.5 products, with around 65% of the gaps shorter than 30 days.
- MODIS C5 shows shorter length of gaps, with around 45% of gaps corresponding to only one missing observation. This could be explained by the richer spectral information and the higher spatial resolution of MODIS, as compared to SPOT/VGT or PROBA-V, which is more suitable for cloud screening.

4.3 SPATIAL CONSISTENCY

4.3.1 Visual inspection over sub-continental areas

In addition to the visual inspection of global maps (see section 4.1), zooms over sub-continental areas of PROBA-V SA V1.5 products were displayed and analyzed at a full resolution.

Figure 24 shows examples of full-resolution images for the PROBA-V SA V1.5 for mid of March, 2014. One different albedo (AL-DH and AL-BH for the three spectral regions) is displayed for each sub-continental region.

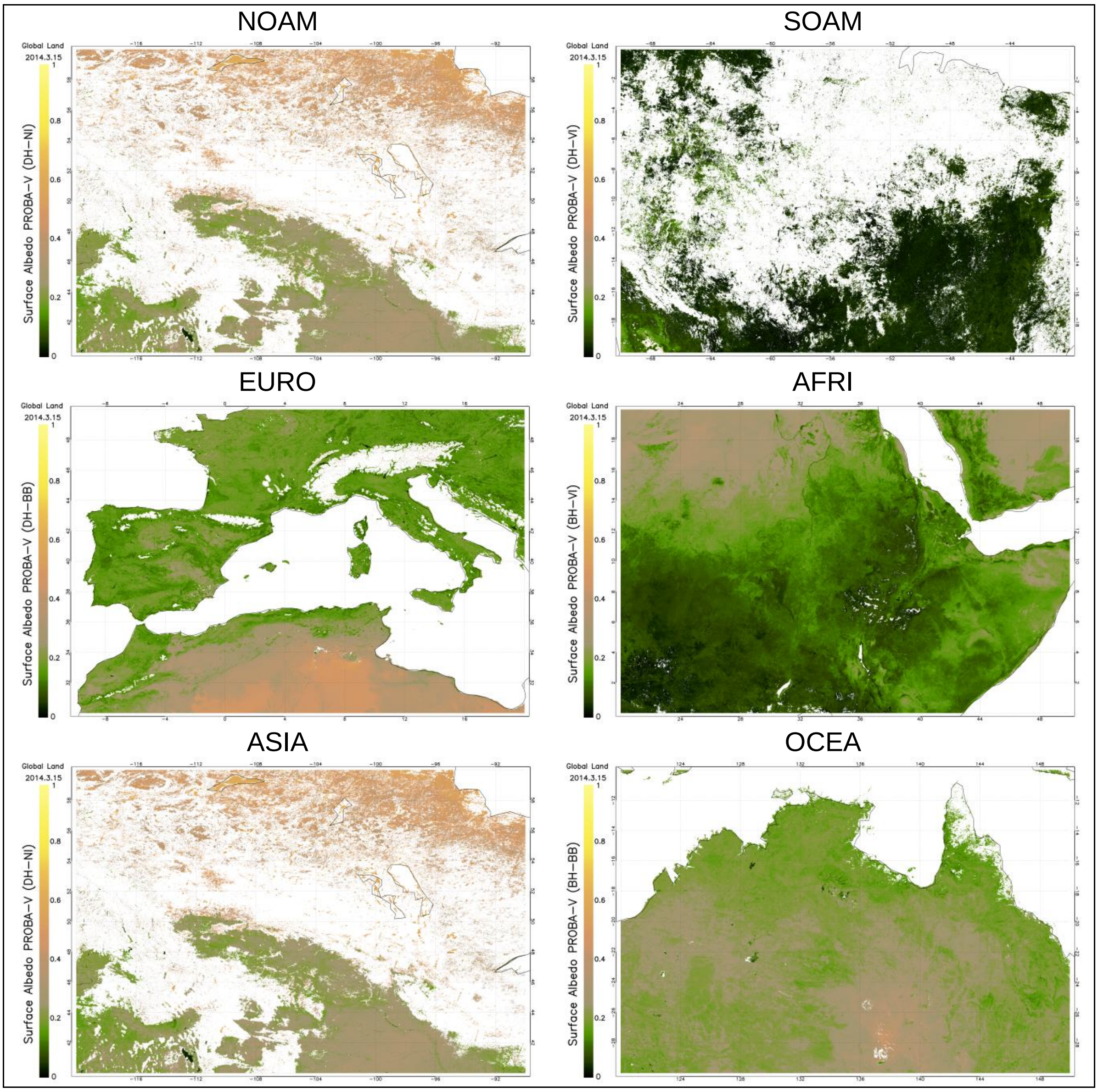


Figure 24: Maps of PROBA-V SA V1.5 products at full resolution over the sub-continental regions of interest (20ºx30º) located in NOAM, SOAM, EURO, AFRI, ASIA and OCEA for mid of March, 2014.

As observed in Figure 24, smooth spatial distributions of the PROBA-V SA V1.5 products were generally observed in all the spectral regions for both black-sky and white-sky albedos, without observing any spatial artifact.

4.3.2 Global distribution of residuals

The spatial consistency of PROBA-V SA V1.5 as compared to equivalent SPOT/VGT products during the overlap period was evaluated in order to analyze the impact of the change of sensor.

ANNEX II shows the global maps of differences and residuals (one example per month) between PROBA-V and SPOT/VGT products for the overlap period.

Main conclusions from the maps of differences in ANNEX II are:

- For visible domain, no systematic positive bias was found for AL-DH-VI and AL-BH-VI between PROBA-V and SPOT/VGT around the whole globe with the exception of bare areas, where slight tendency towards positive differences was found (PROBA-V > SPOT/VGT). Histograms of differences are centered at zero, with 90% and 87% of AL-DH-VI and AL-BH-VI differences within ±0.025.
- For the near infrared, black-sky and white-sky albedos showed positive bias around the whole globe between PROBA-V and SPOT/VGT. The exceptions were the northern latitudes, affected by snow, where random distributions of the sign were found. Histograms of differences are typically centered on~0.02, with 69% and 61% of AL-DH-NI and AL-BH-NI differences within ±0.025.
- Finally, for the total spectrum, PROBA-V black-sky and white-sky albedos tend to provides higher values than SPOT/VGT around the whole globe except over snow pixels (random sign of the bias). Histograms of differences are typically centered ~0.02 during the period from December 2013 to March 2014, and centered at zero during April and May 2014. 84% and 77% and pixels showed differences within ±0.025 for black-sky and white-sky albedos respectively.

Figure 25, Figure 26 and Figure 27show the maps of residuals (Top-left) and global distribution of residuals as a function of the predefined uncertainty levels (Bottom-left, see Table 4) for mid of April. The histograms of residuals at monthly basis period and the percentage of residuals lying the uncertainty levels are also displayed at the right of these figures. Note that these results are only showed for black-sky albedos for the sake of brevity, but similar results were found for white-sky albedos.

For visible domain (Figure 25):

- 90.6% of AL-DH-VI residuals (86.9% in case of AL-BH-VI) lower than 0.025 were found over large areas around the globe, showing large magnitude of residuals mainly over snow pixels in northern regions.
- In average, typically around 36% of AL-DH-VI residuals (30% in case of AL-BH-VI) showed optimal spatial consistency and around 60% (53%) considering the target uncertainty level.
- Pixels showing threshold level (~36%) and poor spatial consistency (~4%) were randomly distributed around the globe, with the exception of arid and semi-arid regions, where optimal spatial consistency was generally found.

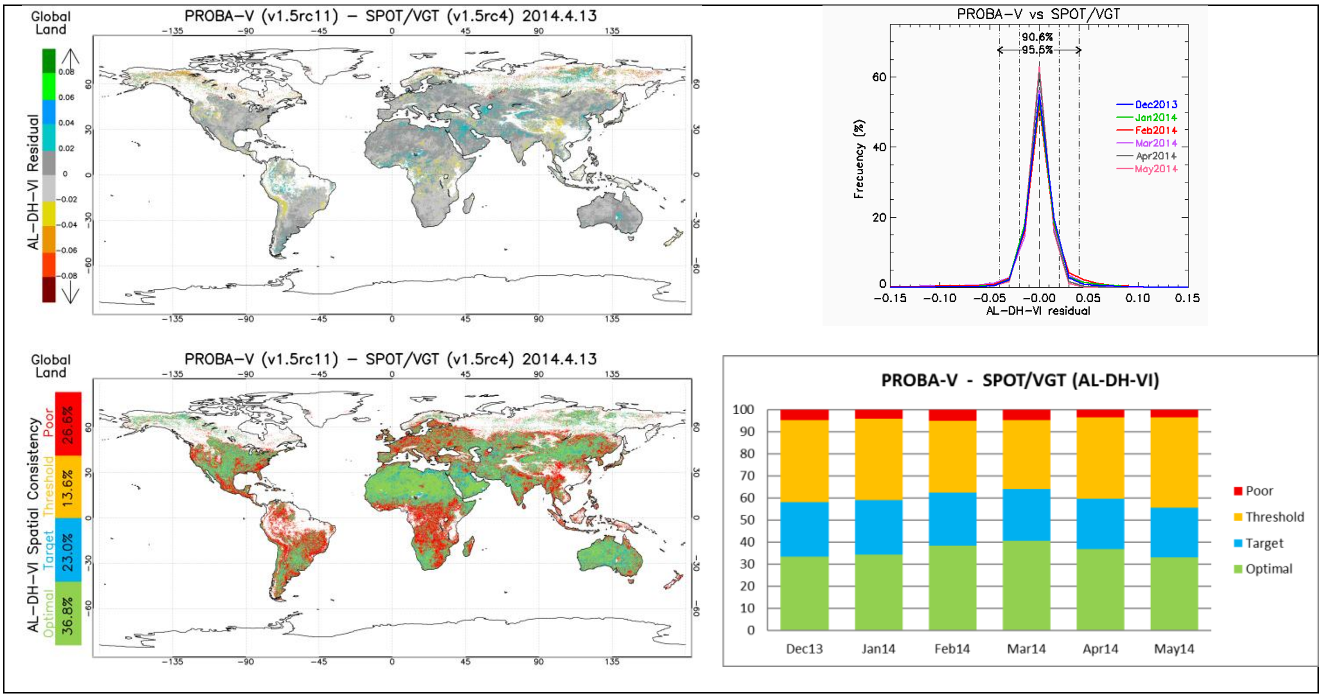


Figure 25: AL-DH-VI residual map (Top-left) and global distribution of residuals lying the uncertainty levels (Bottom-left) between PROBA-V and SPOT/VGT SA V1.5 for 13th April, 2014. Histogram of residuals per month from December 2013 to May 2014 (Top-right) and percentage of residuals lying the uncertainty levels of consistency (Bottom-right).

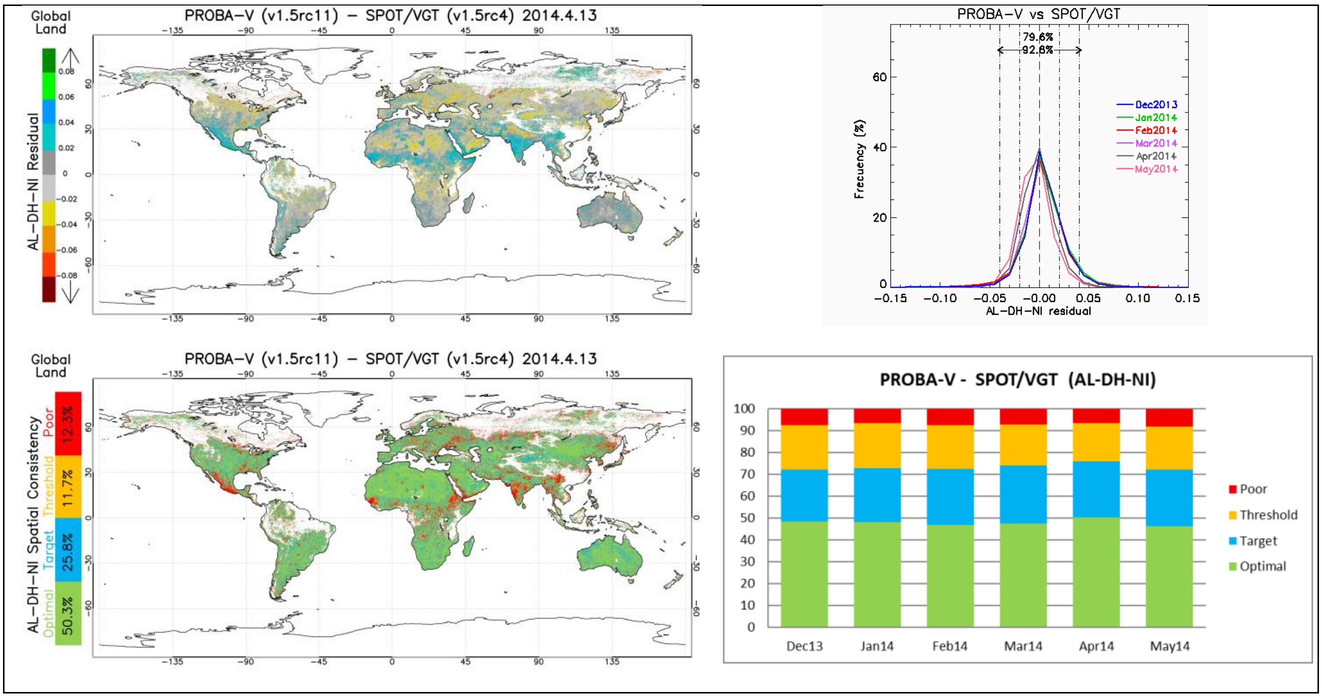


Figure 26: As in Figure 25 for AL-DH-NI.

For the near infrared (Figure 26):

- PROBA-V versus SPOT/VGT residuals are typically ranging between ±0.04 around the whole globe, showing larger magnitudes over snow areas. Histograms of residuals are centered at zero, showing 79.6% and 70.6% of AL-DH-NI and AL-BH-NI pixels within ±0.025.
- In average, typically around 48% of AL-DH-NI residuals (43% in case of AL-BH-NI) showed optimal consistency and around 74% (68%) considering also the target uncertainty level.
- Only ~7% for AL-DH-NI and ~10% for AL-BH-NI pixels showed poor spatial consistency. As observed for the visible spectral domain, poor spatial consistency was randomly distributed around the globe, with the exception of Sahara and Arabian deserts, where optimal spatial consistency was generally found.

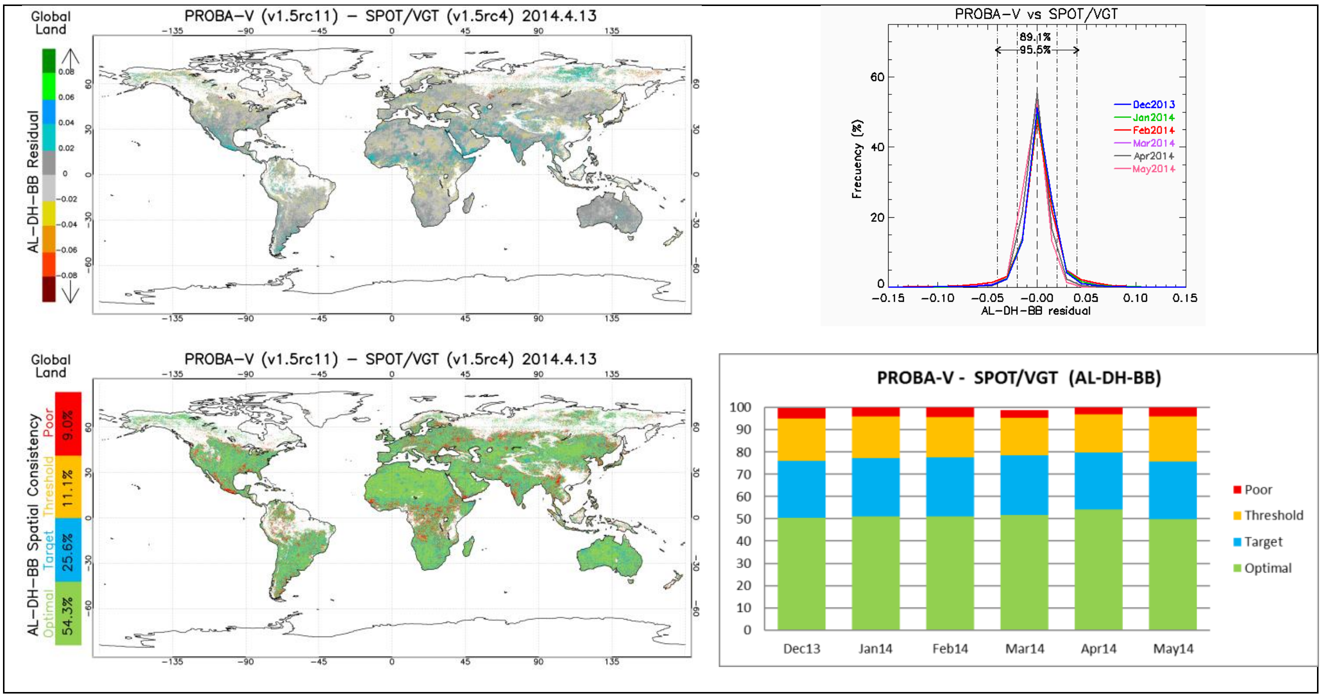


Figure 27: As in Figure 25 for AL-DH-BB.

Finally, for shortwave spectral domain (Figure 27):

- Residuals between PROBA-V and SPOT/VGT are typically ranging between ±0.025 (89.1% of cases for black-sky, and 82.3% for black-sky) with the exception of snow pixels, where large spatial discrepancies were found.
- Optimal consistency was found in more than the half of global pixels for black-sky and white-sky albedos, with ~75% of cases considering the target level.

- In average, only around 4% and 6% of pixels showed poor level of consistency for AL-DH-BB and AL-BH-BB, randomly distributed around the globe with the exception of arid and semi-arid areas where optimal consistency is generally found.

4.3.3 Spatial autocorrelation

Table 16, Table 17 and Table 18 show the maps of the PROBA-V SA V1.5, SPOT/VGT SA V1.5 and MODIS C5 products for AL-DH-VI, AL-DH-NI and AL-DH-BB over the 6 selected AOIs of 50x50 km^2 around homogenous LANDVAL sites (see section 3.5), and their respective spatial indicators: Moran's Index (MI) corresponding to the spatial autocorrelation and Coefficient of Variation (CV). The results show:

- Positive spatial correlation (MI) was found in all cases for these homogeneous areas, with slightly better results (higher MI) of SPOT/VGT and MODIS C5 than PROBA-V in almost all of cases. SPOT/VGT shows, in all cases, the best spatial homogeneity in terms of spatial correlation (higher MI).

Regarding the results in terms of spatial variability (CV), the three products under study provides similar results (same level of magnitude), but PROBA-V tends to provide higher CV than both references in most cases.

Table 16: Maps of PROBA-V, SPOT/VGT and MODIS C5 AL-DH-VI products over the 6 selected AOI of 50kmx50km on mid of April 2017 and the respective Spatial Indicators: Moran's Index (MI) and Coefficient of Variation (CV). White pixels on the maps correspond to missing values in the corresponding product.

AL-DH-VI									
AOI	PROBA-V	SPOT/VGT	MODISC5		AOI	PROBA-V	SPOT/VGT	MODISC5	
#1 EBF	MI=0.47 CV=0.0045	MI=0.65 CV=0.0042	MI=0.52 CV=0.0046	0.06 – 0.01	#4 Shrub	MI=0.76 CV=0.0078	MI=0.87 CV=0.0062	MI=0.86 CV=0.0056	0.21 – 0.13
#2 DBF	MI=0.71 CV=0.0034	MI=0.80 CV=0.0048	MI=0.70 CV=0.0040	0.1 – 0.02	#5 Herb.	MI=0.57 CV=0.0035	MI=0.87 CV=0.0029	MI=0.81 CV=0.0037	0.1 – 0.06
#3 NLF	MI=NaN CV=0.0264	MI=NaN CV=0.0186	MI=NaN CV=0.0306	0.5 – 0.2	#6 BA	MI=0.84 CV=0.0055	MI=0.94 CV=0.0048	MI=0.90 CV=0.0036	0.34 – 0.24

Table 17: As in Table 16 for AL-DH-NI.

AL-DH-NI									
AOI	PROBA-V	SPOT/VGT	MODISC5		AOI	PROBA-V	SPOT/VGT	MODISC5	
#1 EBF	MI=0.31 CV=0.0138	MI=0.60 CV=0.0056	MI=0.53 CV=0.0078	0.18 – 0.16	#4 Shrub	MI=0.74 CV=0.0128	MI=0.86 CV=0.0111	MI=0.88 CV=0.0145	0.49 – 0.33
#2 DBF	MI=0.70 CV=0.0076	MI=0.87 CV=0.0072	MI=0.74 CV=0.0069	0.3 – 0.15	#5 Herb.	MI=0.73 CV=0.0076	MI=0.89 CV=0.0062	MI=0.83 CV=0.0072	0.28 – 0.16
#3 NLF	MI=NaN CV=0.0193	MI=NaN CV=0.0143	MI=NaN CV=0.0198	0.44 – 0.16	#6 BA	MI=0.73 CV=0.0064	MI=0.93 CV=0.0107	MI=0.93 CV=0.0059	0.64 – 0.48

Table 18: As in Table 16 for AL-DH-BB.

AL-DH-BB									
AOI	PROBA-V	SPOT/VGT	MODISC5		AOI	PROBA-V	SPOT/VGT	MODISC5	
#1 EBF	MI=0.51 CV=0.0084	MI=0.61 CV=0.0043	MI=0.50 CV=0.0048	0.18 – 0.1	#4 Shrub	MI=0.75 CV=0.0101	MI=0.87 CV=0.0086	MI=0.86 CV=0.0089	0.34 – 0.24
#2 DBF	MI=0.68 CV=0.0040	MI=0.86 CV=0.0054	MI=0.67 CV=0.0039	0.21 – 0.09	#5 Herb.	MI=0.73 CV=0.0056	MI=0.89 CV=0.0046	MI=0.81 CV=0.0049	0.2 – 0.12
#3 NLF	MI=NaN CV=0.0215	MI=NaN CV=0.0143	MI=NaN CV=0.0238	0.49 – 0.19	#6 BA	MI=0.79 CV=0.0055	MI=0.94 CV=0.0077	MI=0.92 CV=0.0044	0.5 – 0.4

4.4 Temporal consistency analysis

4.4.1 Temporal variations

Temporal profiles of the different surface albedo products (PROBA-V V1.5, SPOT/VGT V1.5 and MODIS C5) were analyzed over the 725 LANDVAL sites (see section 3.4) for each main biome type. From Figure 28 to Figure 34, two sites were selected to illustrate the typical variation of black-sky albedos in visible, near infrared and total spectrum. An additional selection of temporal profiles of white-sky albedos can be found in ANNEX III, and all the temporal profiles in the Digital Annex. All the satellite products are displayed at the centre of their temporal composite window (30 days in case of SPOT/VGT and PROBA-V, and 16 days in case of MODIS C5). The spatial support used was the primary spatial resolution of PROBA-V and SPOT/VGT products (1km^2). Note that the information of the PROBA-V QFLAG was also used in these graphs: filled dots correspond to pixels flagged as good quality, and unfilled dots to pixels flagged as low quality (land pixels with bit 6 or 10 or 11 to 1) according to Table 9.

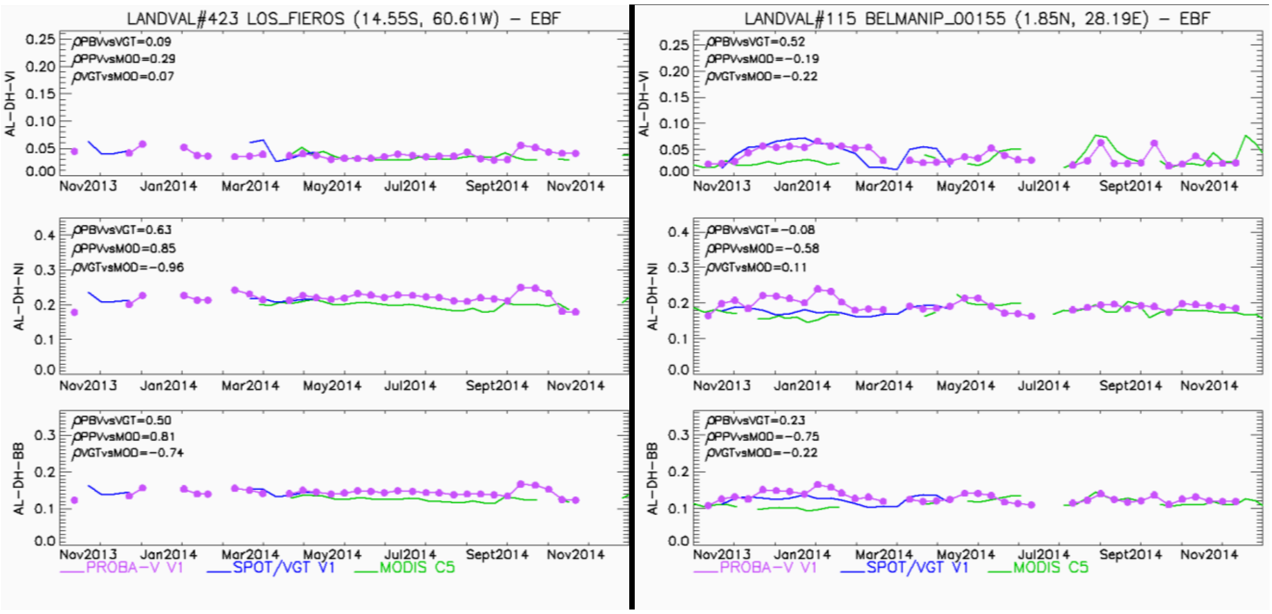


Figure 28: Temporal profile of MODIS C5, SPOT/VGT V1.5 and PROBA-V V1.5 SA products over two selected LANDVAL sites of EBF biome type. From the Top to the Bottom: AL-DH-VI, AL-DH-NI and AL-DH-BB. In case of PROBA-V, filled dots correspond to 'good quality' pixels and unfilled dots to pixels flagged as 'low quality' according to QFLAG.

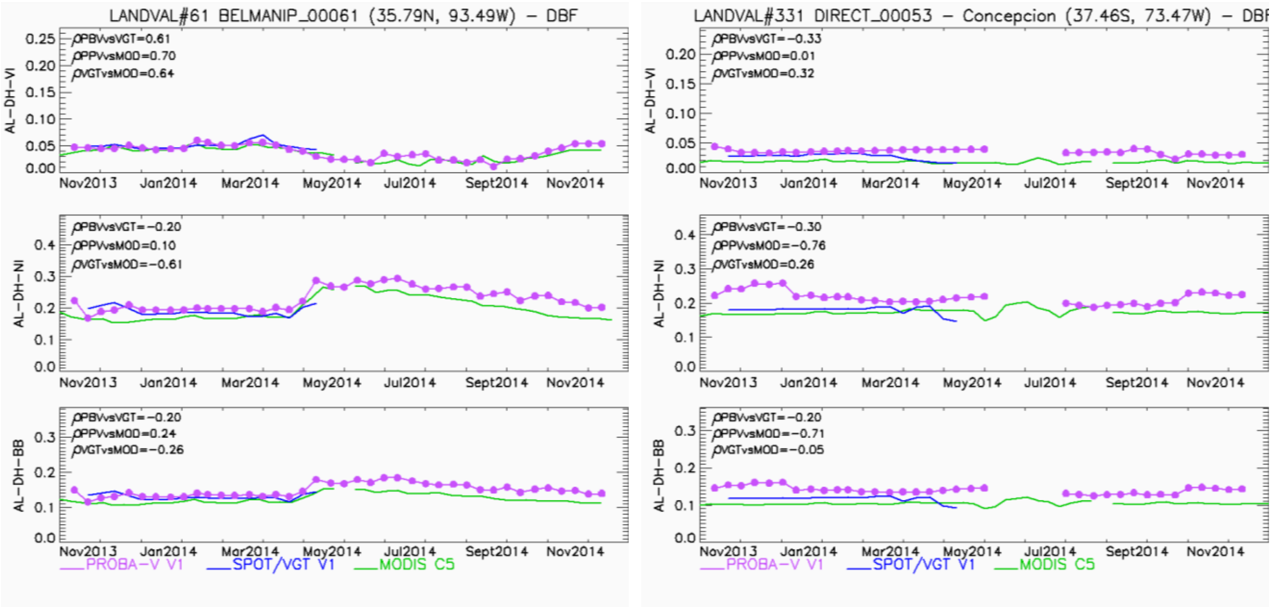


Figure 29: As in Figure 28 for DBF.

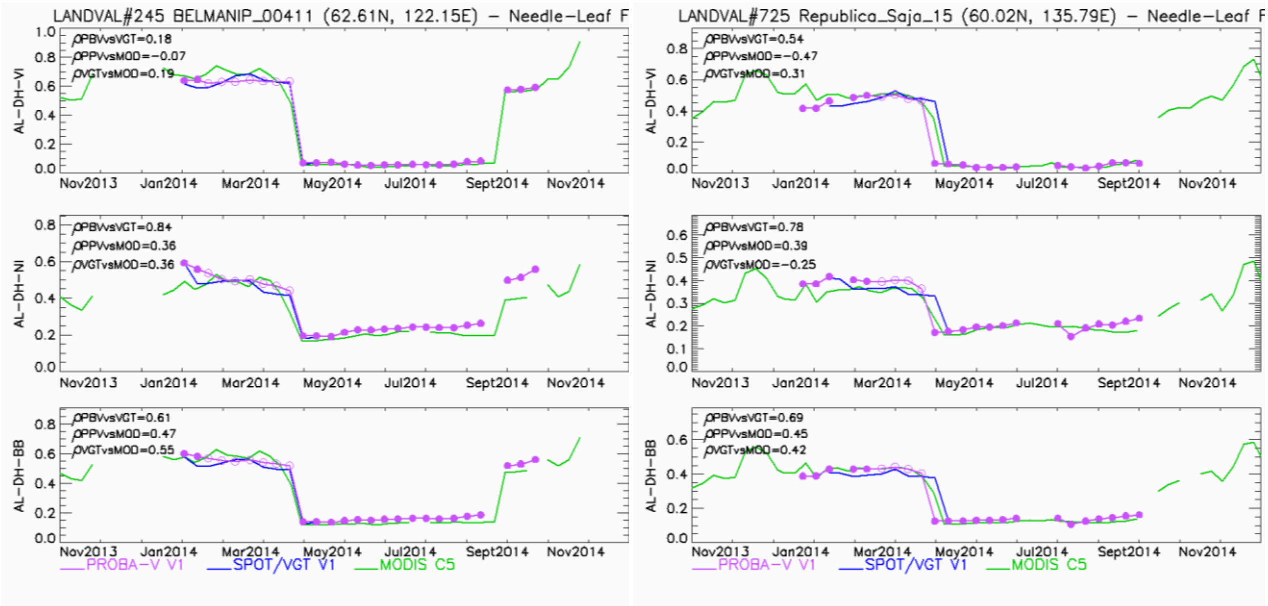


Figure 30: As in Figure 28 for NLF.

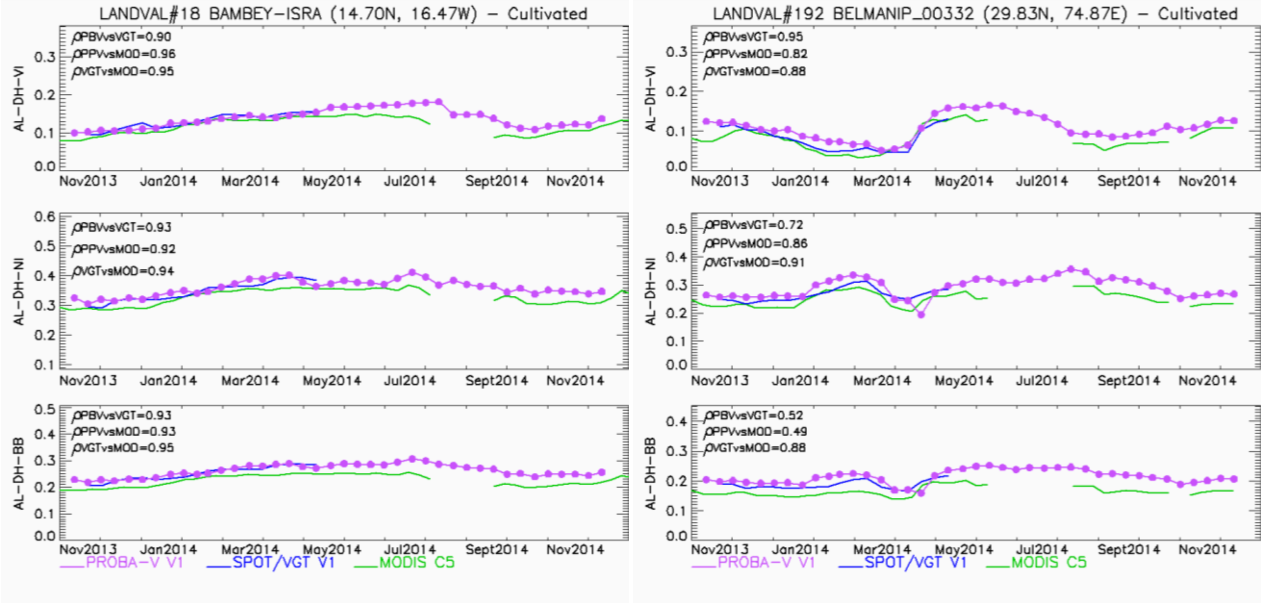


Figure 31: As in Figure 28 for Cultivated.

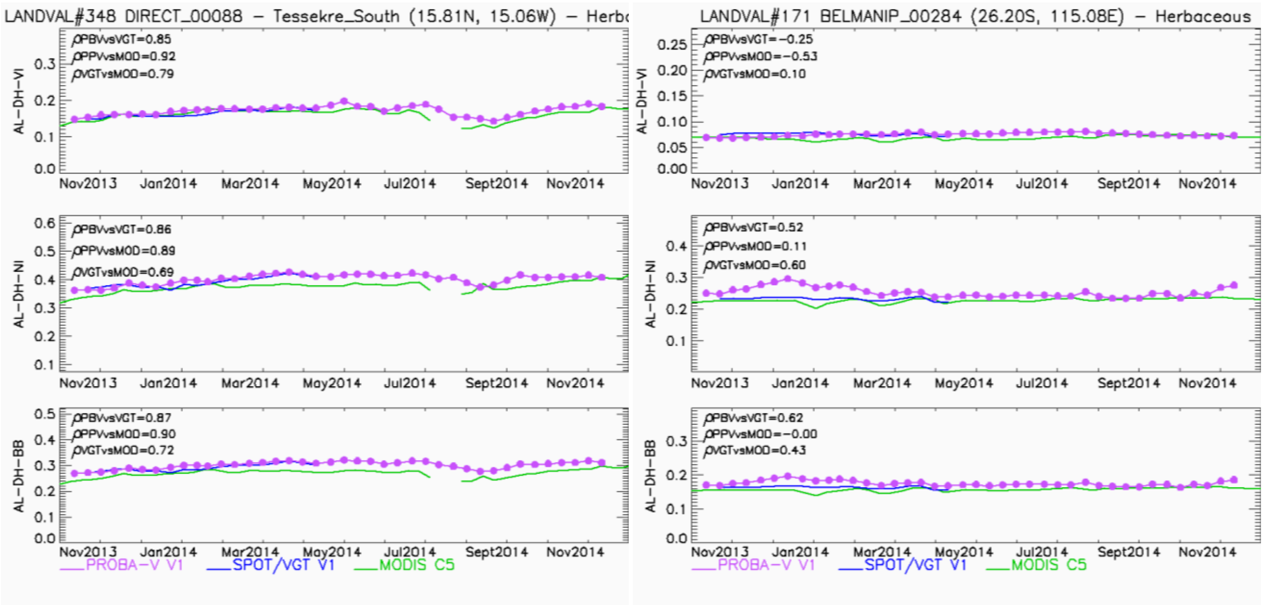


Figure 32: As in Figure 28 for Herbaceous.

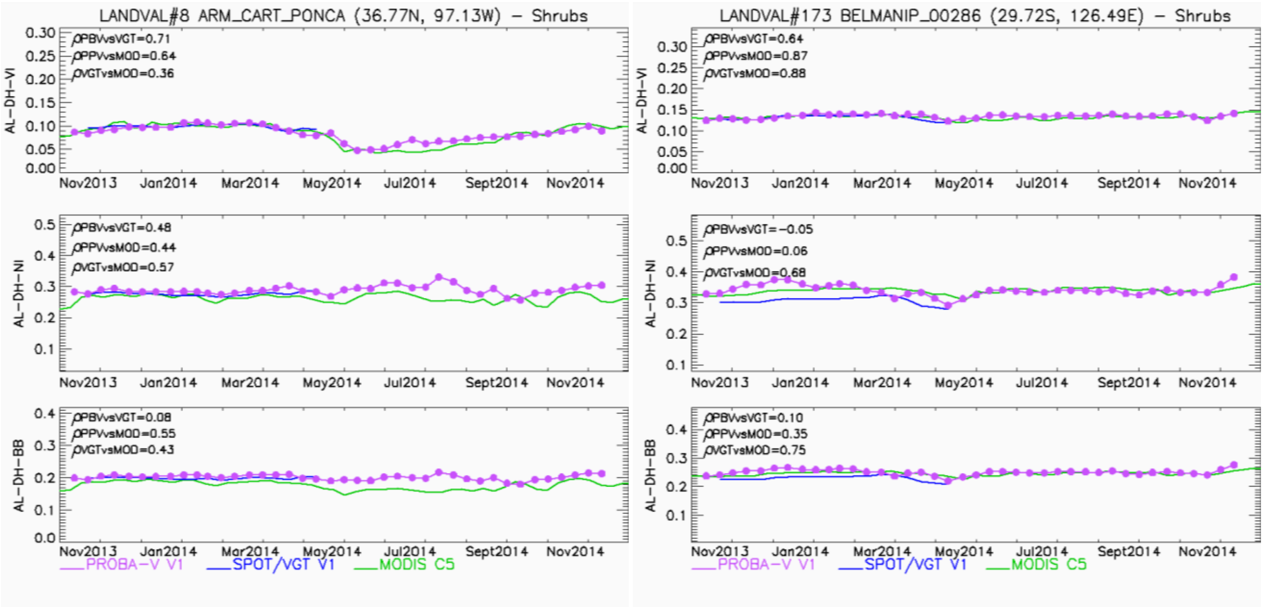


Figure 33: As in Figure 28 for Shrublands.

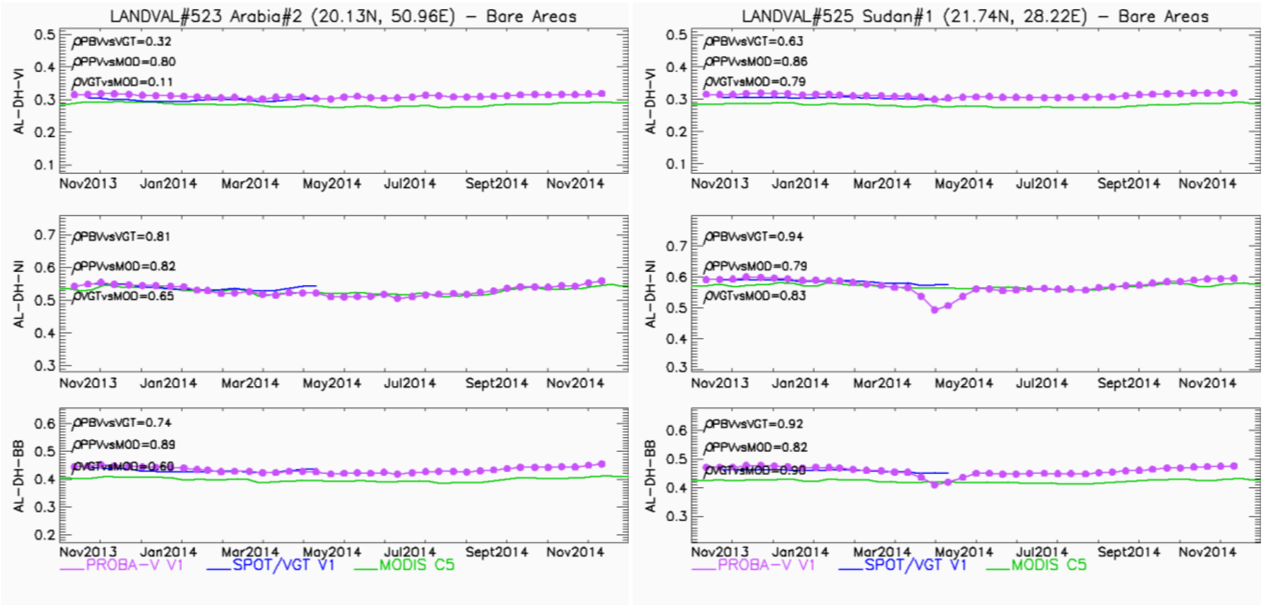


Figure 34: As in Figure 28 for Bare Areas.

- For EBF (Figure 28):
  - Similar temporal trend was found between PROBA-V and both references (SPOT/VGT and MODIS C5), displaying generally low temporal variability (see LANDVAL#423 in Figure 28 or LANDVAL#10 in ANNEX III) in approximately the half of cases. As expected from results of section 4.2, it can be noted that PROBA-V displays more invalid

data than both references, partly explained as a result of a conservative PROBA-V cloud detection.
  - For the rest of cases, some temporal noise was observed in all satellite products (see LANDVAL#115 in Figure 28 or LANDVAL#107 in ANNEX III), explained in the fact that this biome type is typically located over equatorial areas, and lower temporal stability could be indicative of cloud contamination. As observed in the temporal trajectories, the visible spectral domain is more affected by the temporal noise than the rest of spectral domains.
- For DBF (Figure 29):
  - PROBA-V products fit temporally to the trends of SPOT/VGT and MODIS C5 in around 85% of cases. The temporal good consistency was found for both typical temporal trend of this biome type: stable targets at short time and rapid changes of reflectance values due to seasonal variations (see LANDVAL#61 in Figure 29 or LANDVAL#564 in ANNEX III).
  - However, in around 15% of LANDVAL DBF sites, PROBA-V displays slight variability compared to flat temporal trajectories of both references in NIR domain (also affecting to the total spectrum). This effect was observed during the period from November to January (see LANDVAL#331 in Figure 29 or LANDVAL#697 in ANNEX III) over sites located in southern hemisphere (i.e. summer season). This effect could be explained by the different spectral response of the different sensors in NIR domain. The growth of leaves in summer increases the NIR reflectance and, in consequence the albedo in NIR domain.
- For NLF biome type, typically located over northern regions:
  - PROBA-V was found temporally consistent with both references; well reproducing rapid changes of albedo due to snow events (see LANDVAL#245 in Figure 30).
  - Note that the use of Quality Flag in northern latitudes removes valid snow observations in some cases(see LANDVAL#245 and #725 in Figure 30). For this reason, the use of the QFLAG (see Table 9) is not recommended for snow applications. This trend of the Quality Flag, removing valid snow observations over northern latitudes, was also observed for the other biome types (see Cultivated LANDVAL#76, Herbaceous LANDVAL#73 or Shrublands LANDVAL#71 in ANNEX III).
  - In around 10% of cases, a temporal shift corresponding to one dekad was observed between PROBA-V and SPOT/VGT during the dates showing transition between snow and snow-free season (see LANDVAL #725 in Figure 30). This could be partly explained in the different availability of number of observations (NMOD) during the temporal composites.
- Regarding the temporal profiles over cultivated sites (Figure 31), good temporal agreement was found between PROBA-V and both references (SPOT/VGT and MODIS), reproducing well the phenology of the cultivated areas.

- Similar results were found for herbaceous (Figure 32), with PROBA-V showing consistent temporal trajectories as compared to references SPOT/VGT and MODIS. However two kinds of drawback were observed:
    - As observed for DBF, PROBA-V displays some temporal variability during some periods of time where both references provide flat temporal trajectories (see LANDVAL#171 in Figure 32. This effect was mainly observed in NIR domain (also affecting to the total spectrum) during the period from November to January over southern hemisphere (summer season) in around 12% of LANDVAL cases.
    - The snow event in both reference products (SPOT/VGT and MODIS C5) was not properly captured in PROBA-V in 10% of LANDVAL cases (see Herbaceous LANDVAL#375 in ANNEX III).
- For shrublands, PROBA-V was found temporally consistent with both satellite references in 80% of cases. However, as observed for DBF and Herbaceous, PROBA-V provides some temporal variability as compared to both references (flat temporal profiles) in NIR domain during the period from November to January in southern hemisphere. This effect was observed in 20% of LANDVAL cases of shrublands.
- Finally, for bare areas, consistent PROBA-V temporal trajectories were found compared with both references, providing stable temporal trends as showed in the desertic calibration sites LANDVAL#523 (Figure 34). However, in few cases (12%) over LANDVAL sites, some temporal noise was observed in case of PROBA-V (near infrared) compared with both references (see sudden drop of PROBA-V in LANDVAL#525 in Figure 34 or LANDVAL#533 in ANNEX III).

4.4.2 Cross-correlation distributions

The cross-correlation of the temporal variations between PROBA-V, SPOT/VGT and MODIS black-sky albedos during the overlap period (December 2013 - May 2014) was assessed per biome type for the LANDVAL sites for visible (Figure 35), near infrared (Figure 36) and total spectrum (Figure 37). Cross-correlations distributions for white-sky albedo are presented in ANNEX IV, showing similar results.

Main conclusions are:

- For visible spectral domain (Figure 35):
    - Cross-correlation between PROBA-V and SPOT/VGT temporal variations was higher than 0.7 in more than 50% of LANDVAL sites for NLF, cultivated, shrublands and herbaceous, and more than 40% LANDVAL sites for the rest of biomes.
    - The correlations between PROBA-V and MODIS AL-DH-VI variations are slightly lower, but satisfactory (>0.7 in ~50% of cases), except for EBF type and snow.
    - Similar results were found in the comparison of PROBA-V versus MODIS than in the comparison of SPOT/VGT versus MODIS for DBF, NLF, cultivated, shrublands, and

herbaceous. PROBA-V and MODIS are more correlated in bare areas, and the opposite (SPOT/VGT and MODIS are more correlated) was found over snow. Poor correlations were found between both CGLS products and MODIS over EBF.

- For the near-infrared (Figure 36):
  - Cross-correlation between PROBA-V and SPOT/VGT temporal variations was higher than 0.7 in typically around 50% of LANDVAL sites for DBF, shrubs, herbaceous and bare areas. Poor correlation was found for EBF (10%) and snow (30%). The best results were found for NLF and cultivated, with 67% and 58.5% of LANDVAL sites showing cross-correlations higher than 0.7.
  - Lower cross-correlations were found between PROBA-V and MODIS AL-DH-NI variations, with typically less than 40% of cases showing cross-correlation higher than 0.7. The exceptions were DBF (42.1%) and NLF (66%).
  - Similar results were found in the comparison of PROBA-V versus MODIS than in the comparison of SPOT/VGT versus MODIS for forest sites and bare areas, whereas significant better results were found in the comparison of SPOT/VGT and MODIS for the rest of biome types.

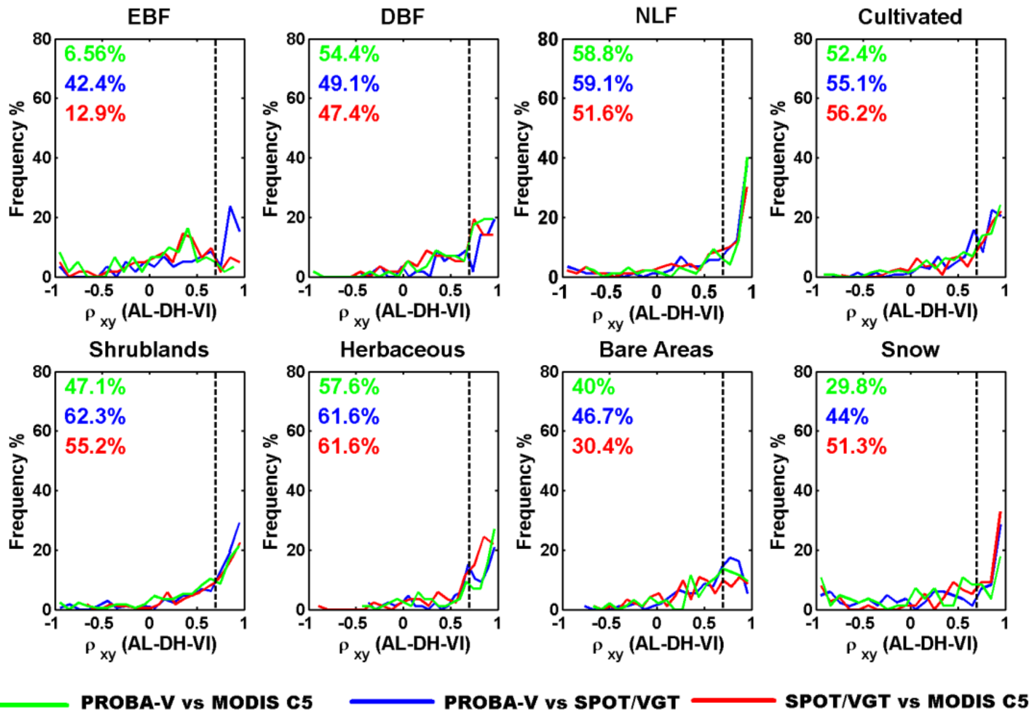


Figure 35: AL-DH-VI cross-correlation distributions (ρ_{XY}) between pair of products (PROBA-V, SPOT/VGT and MODIS C5) temporal profiles for LANDVAL sites during December 2013 – May 2014 period for each biome type. The values in each plot shows the percentage of cases with correlations higher than 0.7.

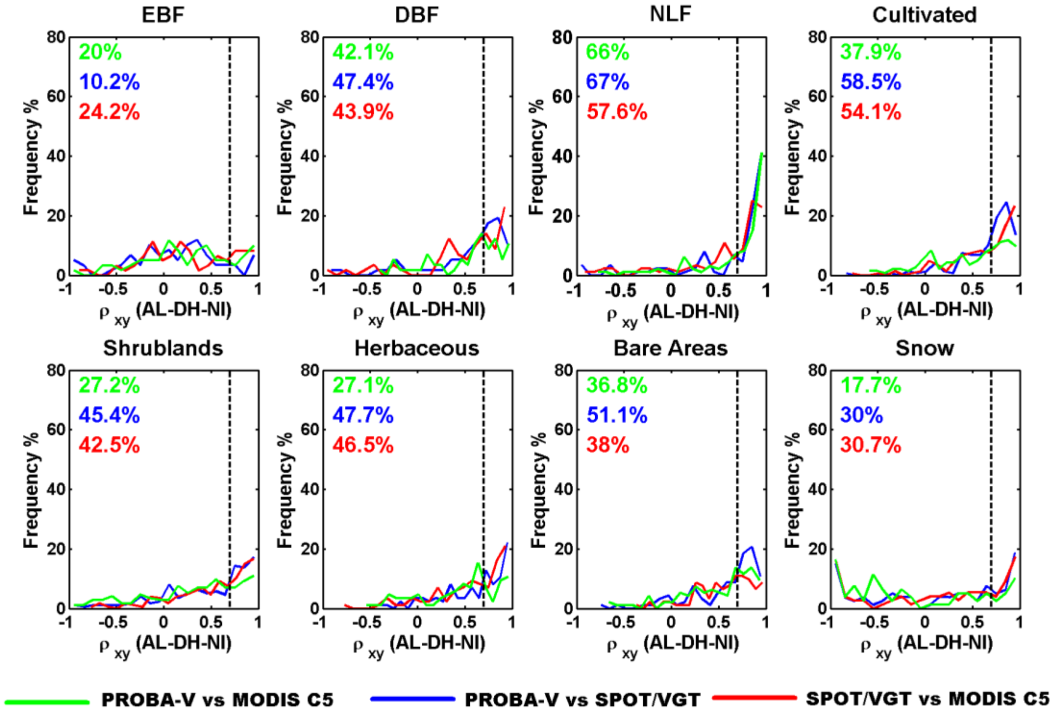


Figure 36: As in Figure 35 for AL-DH-NI.

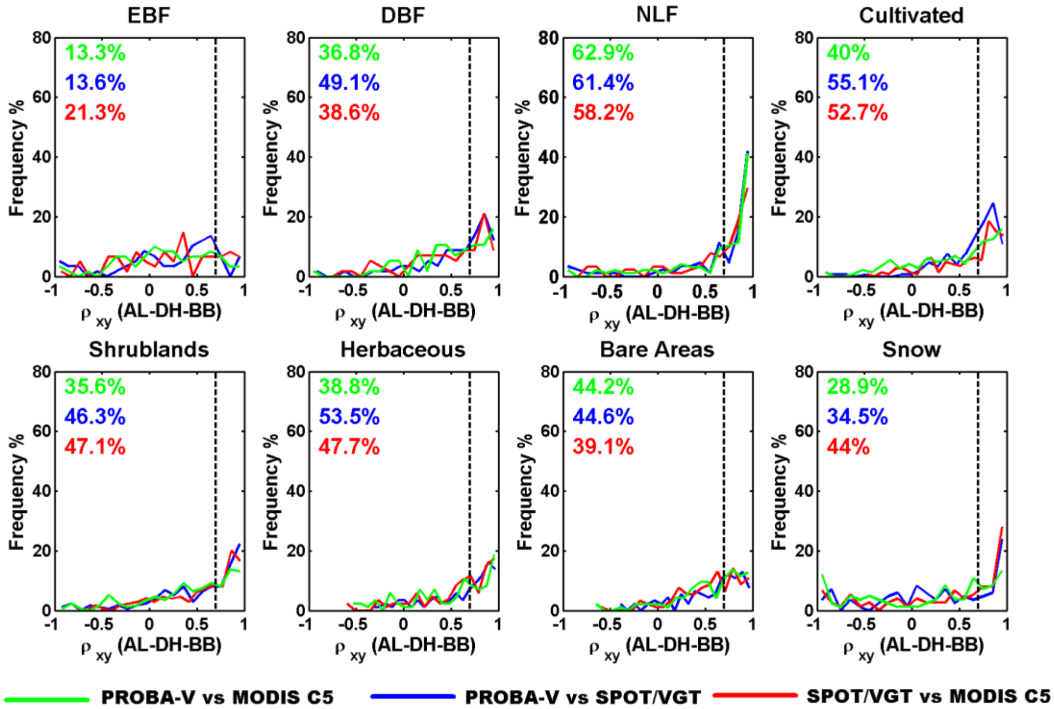


Figure 37: As in Figure 35 for AL-DH-BB.

- Finally, for the shortwave (Figure 37):
  - As observed for NIR, cross-correlations between PROBA-V and SPOT/VGT temporal variations was higher than 0.7 in typically around 50% of LANDVAL sites for most of biome types (DBF, cultivated, shrubs, herbaceous and bare areas), showing the best performance in NLF (61.4%). Poor correlation was found for EBF (13.6%) and snow (34.5%).
  - Slight lower cross-correlations were found between PROBA-V and MODIS, with typically around 40% of cases showing cross-correlation higher than 0.7 and showing the best performance in NLF (62.9%) and poor correlations in EBF (13.3%).
  - PROBA-V tends to provide worse results as compared with MODIS than SPOT/VGT for all biome type except for bare areas.

4.4.3 Temporal realism

Temporal profiles of the different products under study were analyzed over sites coming from 17 SURFRAD and EFDC sites where ground data information was available (see Table 11). To evaluate the temporal realism of satellite products the blue-sky albedo ground data measured at the stations was displayed, and qualitatively compared with AL-DH-BB satellite retrievals at 1km^2 of spatial resolution. Figure 38 displays 8 examples and the rest of 9 temporal profiles of the stations presented in Table 11 are displayed in ANNEX V.

Main conclusions are:

- Most of the snow events detected in ground data are well reproduced in PROBA-V products. However, PROBA-V tends to provide lower number of satellite estimations than SPOT/VGT and MODIS C5 during dates showing snow event (see '*Sioux Falls'* and '*Monte Bondone'* in Figure 38, or '*Zackenberg Heat'* in ANNEX V). In some cases ('*Bondville'* and *'Boulder'* in ANNEX V) PROBA-V does not provide valid retrievals during the snow season.
- Over sites where low variability of albedo values was observed along the time during some period, PROBA-V products provides also low variability (see '*Sioux Falls'*, '*Cortes de Pallas'* and '*Monte Bondone'* in Figure 38, or '*Boulder', 'Fort Peck'* and *'Tharandt'* in ANNEX V). However, in some cases (see '*Desert Rock'* and '*Puechabon*' in Figure 38), PROBA-V provides some temporal noise as compared with ground values and satellite references products.

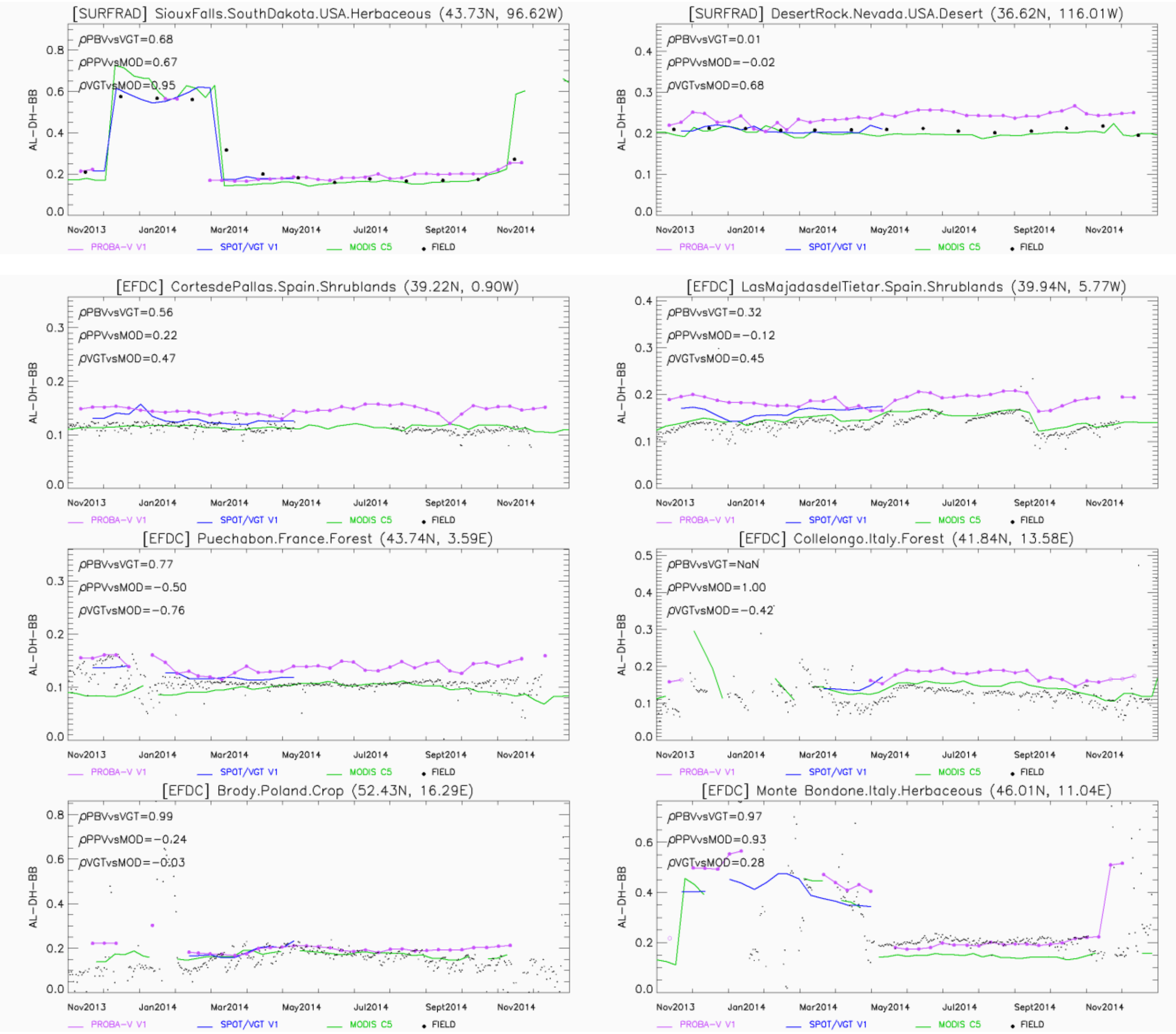


Figure 38: Temporal profiles of MODIS C5, SPOT/VGT V1.5 and PROBA-V V1.5 surface albedo products (AL-DH-BB) over a selection of SURFRAD and EFDC sites with availability of blue-sky albedo measurements. In case of PROBA-V, filled dots correspond to 'good quality' pixels and unfilled dots to pixels flagged as 'low quality' according to QFLAG.

4.5 INTRA-ANNUAL PRECISION

Figure 39 shows the histograms of the smoothness (δ) for the directional albedo in the visible and NIR spectral ranges, and in the total shortwave. The computation was performed over LANDVAL sites during the overlap period between SPOT/VGT, PROBA-V and MODIS products. Note that almost identical results were found for bi-hemispherical albedos.

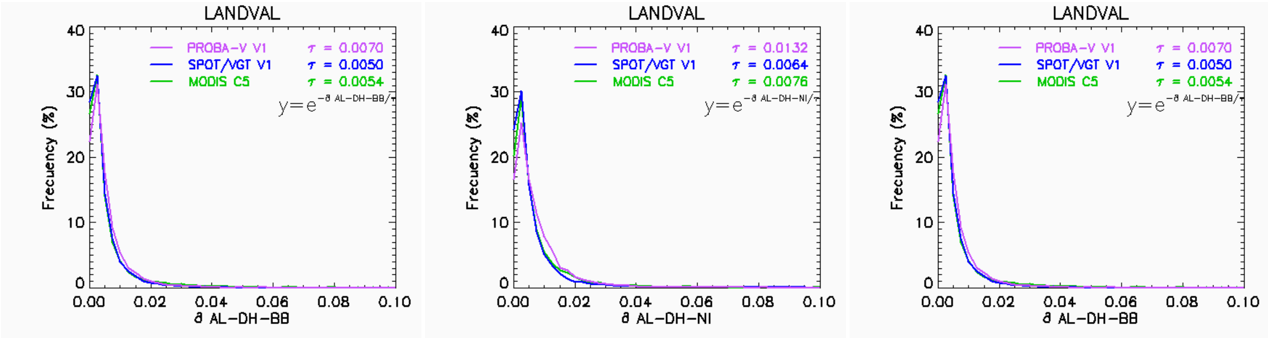


Figure 39: Histograms of the delta function (smoothness) for AL-DH-VI (left), AL-DH-NI (centre) and AL-DH-BB (right) products for LANDVAL sites during the December 2013-May 2014 period. The curves are adjusted to an exponential function and the exponential decay constant (τ) is presented in the figure.

Main conclusions are:

- The three products present very similar distributions. Most of the delta values are below 0.01 which demonstrates the high stability at short time scale of the albedo products.
- However, the higher δ values of PROBA-V albedo products as compared to both references (mainly observed in the NIR) could be also indicative of slightly degraded precision at short time scale. This result confirms the conclusions from the qualitative inspection of temporal trajectories (see section 4.4.1).

4.6 OVERALL SPATIO-TEMPORAL CONSISTENCY

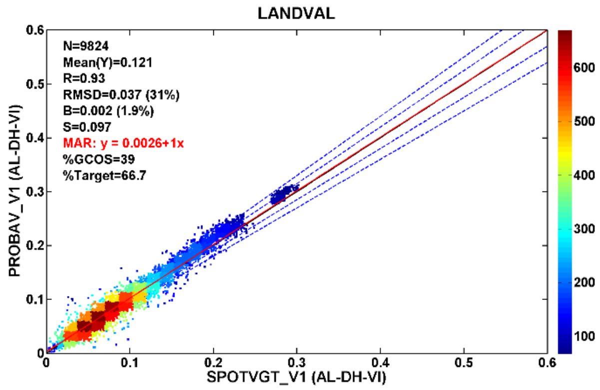
In this section, the spatio-temporal consistency of PROBA-V SA V1.5 products was evaluated against both references: SPOT/VGT (December 2013 – May 2014 period) and MODIS C5 (whole 2014 year). For each comparison, firstly the scatter-plots (and associated metrics) between pair of products are presented, as well as the box-plots of bias and RMSD as a function of the albedo ranges. Secondly, the scatter-plots (and associated metrics) per main biome type are presented. For the sake of brevity, this section presents the results for black-sky albedo, and all the results for white-sky albedos are available in the Digital Annex. Digital Annex also complements the spatio-temporal consistency analysis, providing the histograms of retrievals and histograms of differences for the three products under study per main biome type and continental region. Main conclusion from histograms of retrievals and histograms of differences are:

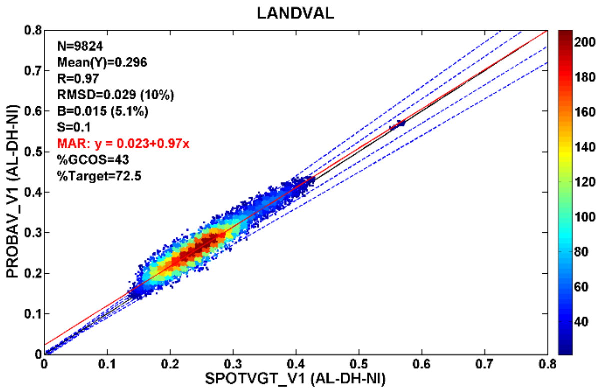
- For visible domain:
  - Similar histograms of retrievals were found between PROBA-V, SPOT/VGT and MODIS C5 for all biome type except for snow.
  - Histograms of differences between PROBA-V and SPOT/VGT are centered at zero for all biome except for herbaceous and bare areas (slight positive bias) and snow (random distributions).

  - Histograms of differences between PROBA-V and MODIS C5 are centered at zero for all biome type except for cultivated (positive bias) and snow (random distributions).
- For near infra-red and shortwave domains:
  - Similar distribution of retrievals was found between PROBA-V and both references, showing some differences in NLF, cultivated, herbaceous and bare areas.
  - Histograms of differences between PROBA-V and both references are generally shifted towards positive bias (higher PROBA-V values) for all biome type except for snow (random distributions).

4.6.1 Overall consistency between PROBA-V and SPOT/VGT (overlap period)

The spatio-temporal consistency between PROBA-V and SPOT/VGT SA V1.5 products was statistically assessed over the LANDVAL network of sites during the overlap period (December 2013 - May 2014). Pixels flagged as 'low quality' in PROBA-V and SPOT/VGT according to Table 9 were removed from the computation. Note that, in case of PROBA-V, this condition removes some of the valid retrievals over snow pixels, as showed in the temporal consistency analysis (see section 4.4.1), and rarely affects to the rest of retrievals.





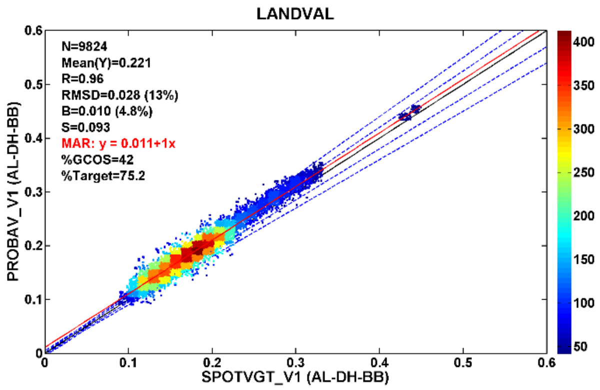


Figure 40: PROBA-V versus SPOT/VGT SA V1.5 products scatter-plots over all LANDVAL sites during the December 2103 - May 2014 period for AL-DH-VI, AL-DH-NI and AL-DH-BB. The computation was done over good quality pixels according to PROBA-V and SPOT/VGT QFLAGs. Dashed lines correspond to the optimal (GCOS), and target (CGLOPS optimal) levels around the 1:1 continuous line.

Figure 40 shows the PROBA-V versus SPOT/VGT SA V1.5 scatter-plots and associated metrics for black-sky albedos. The summary of the performance statistics for black-sky and white-sky albedos is presented in Table 19.

Table 19: Performance statistics of PROBA-V versus SPOT/VGT SA V1.5 products over all LANDVAL sites during December 2103 to May 2014 period. The computation was done over good quality pixels according to PROBA-V and SPOT/VGT QFLAGs.

	PROBA-V vs SPOT/VGT (Dec 2013 – May 2014)					
	AL-DH-VI	AL-DH-NI	AL-DH-BB	AL-BH-VI	AL-BH-NI	AL-BH-BB
Correlation	0.93	0.97	0.96	0.92	0.96	0.95
Bias	0.002 (1.9%)	0.015 (5.1%)	0.01 (4.8%)	0.001 (0.71%)	0.016 (5.2%)	0.01 (4.6%)
RMSD	0.037 (31%)	0.029 (10%)	0.028 (13%)	0.038 (30%)	0.034 (11%)	0.03 (13%)
Offset	0.0026	0.023	0.011	0.001	0.027	0.012
Slope	1	0.97	1	1	0.96	0.99
%optimal (GCOS)	39	43	42	33	39	40
%target (CGLOPS optimal)	66.7	72.5	75.2	57.9	67.9	71.3

The main conclusions from Figure 40 and Table 19 are:

- For visible domain, almost no mean bias was found between PROBA-V and SPOT/VGT black-sky and white sky albedos (1.9% and 0.71%), with number of pixels within the optimal CGLOPS uncertainty requirements of 66.7 and 57.9% (39% and 33% considering GCOS requirements). Optimal lineal regression relationships from the MAR were found (offset ~0 and slope ~1). Worse results were found in terms of RMSD, with values of around 0.04 (30%).
- For the near infrared, positive bias (PROBA-V > SPOT/VGT) of 5% was found, with RMSD of 10% and higher correlations (>0.96). 72.5% and 67.9% of AL-DH-NI and AL-BH-NI retrievals showed CGLOPS optimal level of consistency (43% and 39% considering GCOS requirements).
- Finally, for the total spectrum, positive bias lower than 5% was found between PROBA-V and SPOT/VGT, as well as high correlations (>0.95). For AL-DH-BB and AL-BH-BB, more than 17% of pixels over LANDVAL sites showed CGLOPS optimal consistency (>40% considering GCOS requirements). Total discrepancies (RMSD) of 0.03 (13%) were found.

- **Box-plot of uncertainties per bin**

The analysis of the discrepancies (bias and RMSD) between PROBA-V and SPOT/VGT SA V1.5 products per range of values during the overlap period (December 2013 - May 2014) are presented from Figure 41 to Figure 43 for AL-DH-VI, AL-DH-NI and AL-BH-BB, computed over LANDVAL network of sites. Note that the QFLAG of both products was not used in order to increase the sampling of snow pixels, typically showing the highest albedo values. Note than the range value was computed as the average between both products, and the percentage of pixels within the optimal (GCOS) and target (CGLOPS optimal requirement) predefined uncertainty levels (Figure 2, Table 4) is presented for each range.

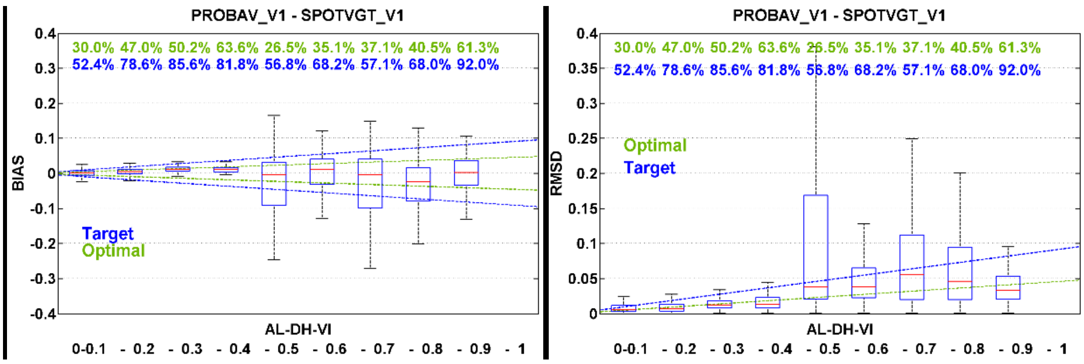


Figure 41: Box-plots of uncertainty statistics between PROBA-V and SPOT/VGT SA V1.5 (Bias: left side, RMSD: right side) per bin for AL-DH-VI during December 2013 to May2014. Red bars indicate median values, blue boxes stretch from the 25thpercentile to the 75thpercentile of the data and whiskers include 99.3% of the coverage data (±2.7 σ). Outliers are not displayed. Green, Blue and orange lines correspond to optimal, target and threshold uncertainty levels, and percentage of pixels within these levels are presented for each bin.

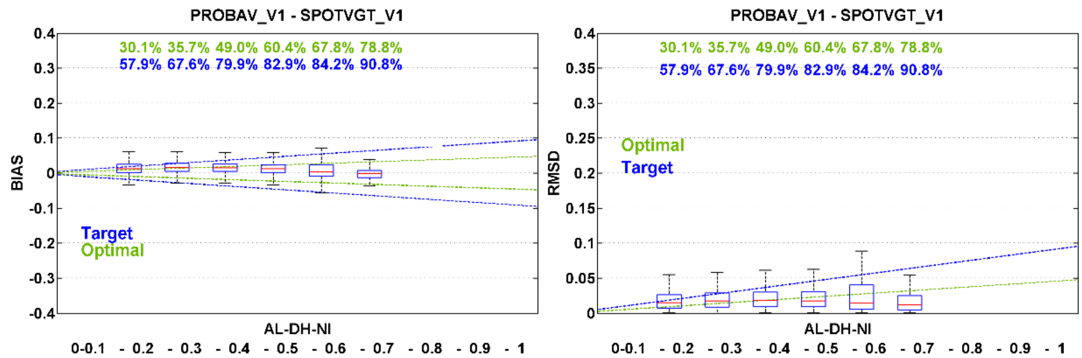


Figure 42: As in Figure 41 for AL-DH-NI.

For the visible domain (Figure 41):

- Box-plots show median bias close to zero for all albedo value, with all median within the optimal (GCOS) level, and without finding systematic trend of the sign of the differences.
- Median RMSD values are within the optimal level of consistency for all albedo ranges except for values between 0.4 and 0.8, where target level was achieved. Large scattering was found for 0.4-0.5 and 0.6-0.8 ranges.

- More than 50% of pixels are within the CGLOPS optimal level of consistency for all albedo ranges except. The best performance in terms of percentage of pixels within the CGLOPS optimal level (>80%) was found for 0.3-0.5 range, and for the highest (>0.8) albedo values (typically snow).
- Similar trend was found for black-sky and white-sky albedos.

For the near infrared (Figure 42):

- PROBA-V tends to provide higher values than SPOT/VGT for all albedo ranges except for albedos higher than 0.6, where median bias close to zero was found, which confirms the global tendency observed at the global differences (see ANNEX II).
- Median bias and RMSD within the target level (CGLOPS optimal level) was found for albedo values lower than 0.3, whereas the optimal level (GCOS) was achieved from 0.3 onwards.
- As the albedo value increases, the percentage within the uncertainty requirements also increases. Percentages within the optimal (target) level of consistency from 30% (58%) to 79% (91%) were found.
- Similar results were found for AL-BH-NI and AL-DH-NI, showing slight number of cases within optimal and target levels in white-sky retrievals.

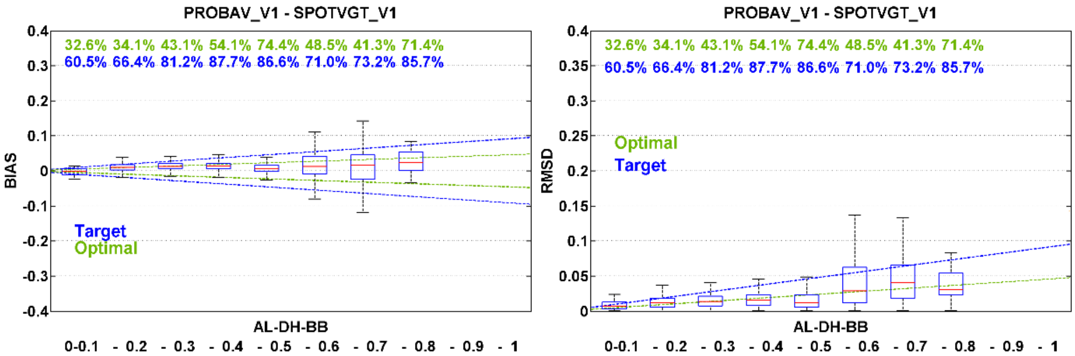


Figure 43: As in Figure 41 for AL-DH-BB.

For the shortwave (Figure 43):

- Systematic positive bias was found for all ranges, with median values within the optimal (GCOS) level of consistency.
- The best agreement was found for 0.3-0.5 range, and for the highest albedo values, with more than 85% of pixels showing the CGLOPS optimal level of consistency. For the rest of ranges, typically more than 60% (albedo<0.1) of pixels within the CGLOPS optimal level were found.
- Similar results were found between AL-BH-BB and AL-DH-BB. However, no values were found for the highest range (0.7-0.8) in case of whit-sky albedo.

4.6.2 Analysis per biome type (PROBA-V versus SPOT/VGT)

Scatter-plots between PROBA-V and SPOT/VGT SA V1.5 products were analyzed per biome type over LANDVAL sites during the overlap period of both products (December 2013 to May 2014) over good quality pixels according to the QFLAG of both products (see Table 9). Note that for the computation of statistics over the snow class, the QFLAG information was not used because most of valid retrievals over snow are removed with the use of QFLAG. Figure 44, Figure 45 and Figure 46 show the scatter-plot for AL-DH-VI, AL-DH-NI and AL-DH-BB respectively. The scatter plots per biome type for white-sky albedos, as well as the analysis per continental region are included in the Digital Annex.

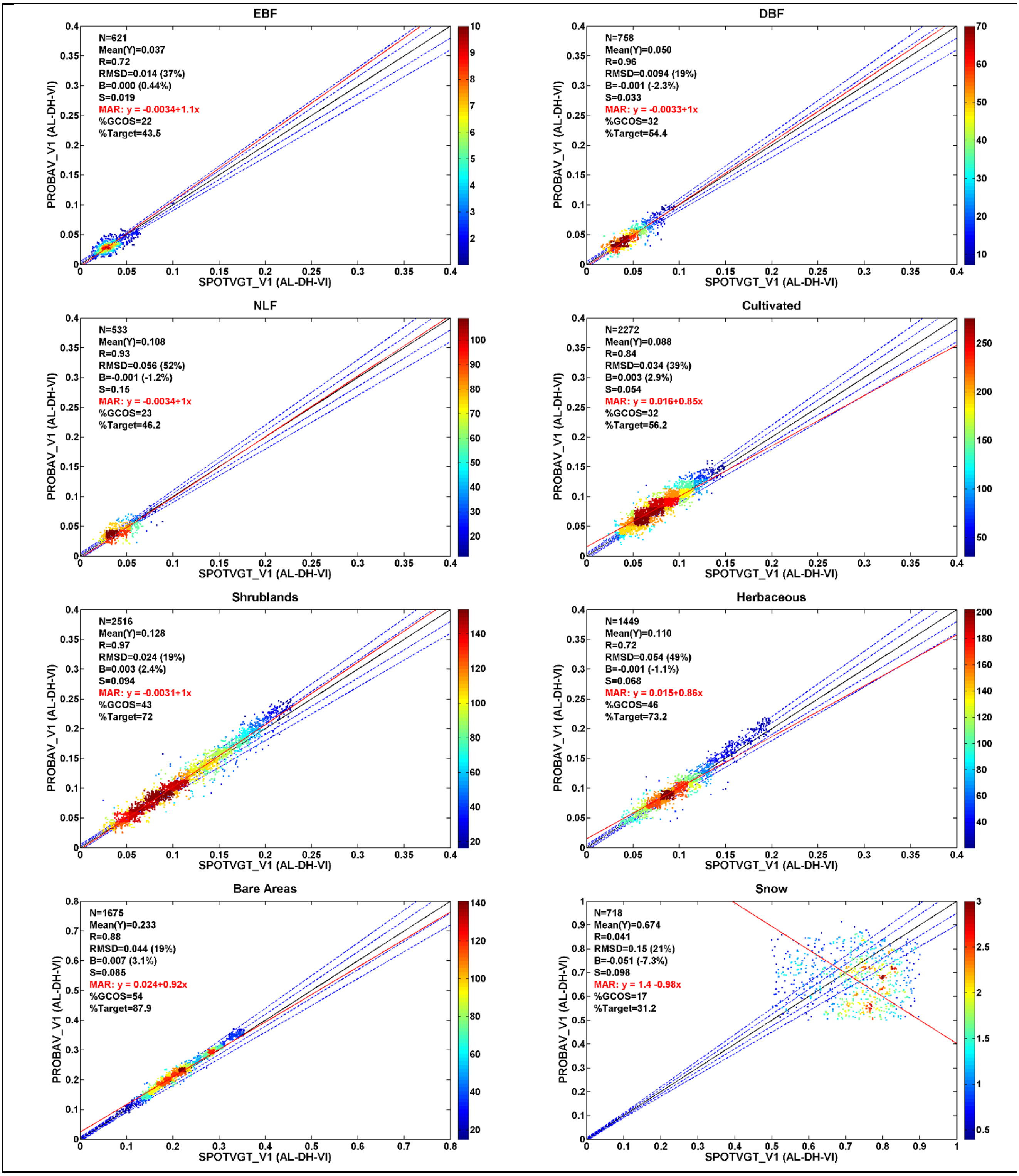


Figure 44: PROBA-V versus SPOT/VGT SA V1.5 (AL-DH-VI) products scatter-plots over LANDVAL sites for the December 2013 - May 2014 period for each land cover type. Dashed lines correspond to the optimal (GCOS) and target (CGLOPS optimal) uncertainty levels around the 1:1 continuous line.

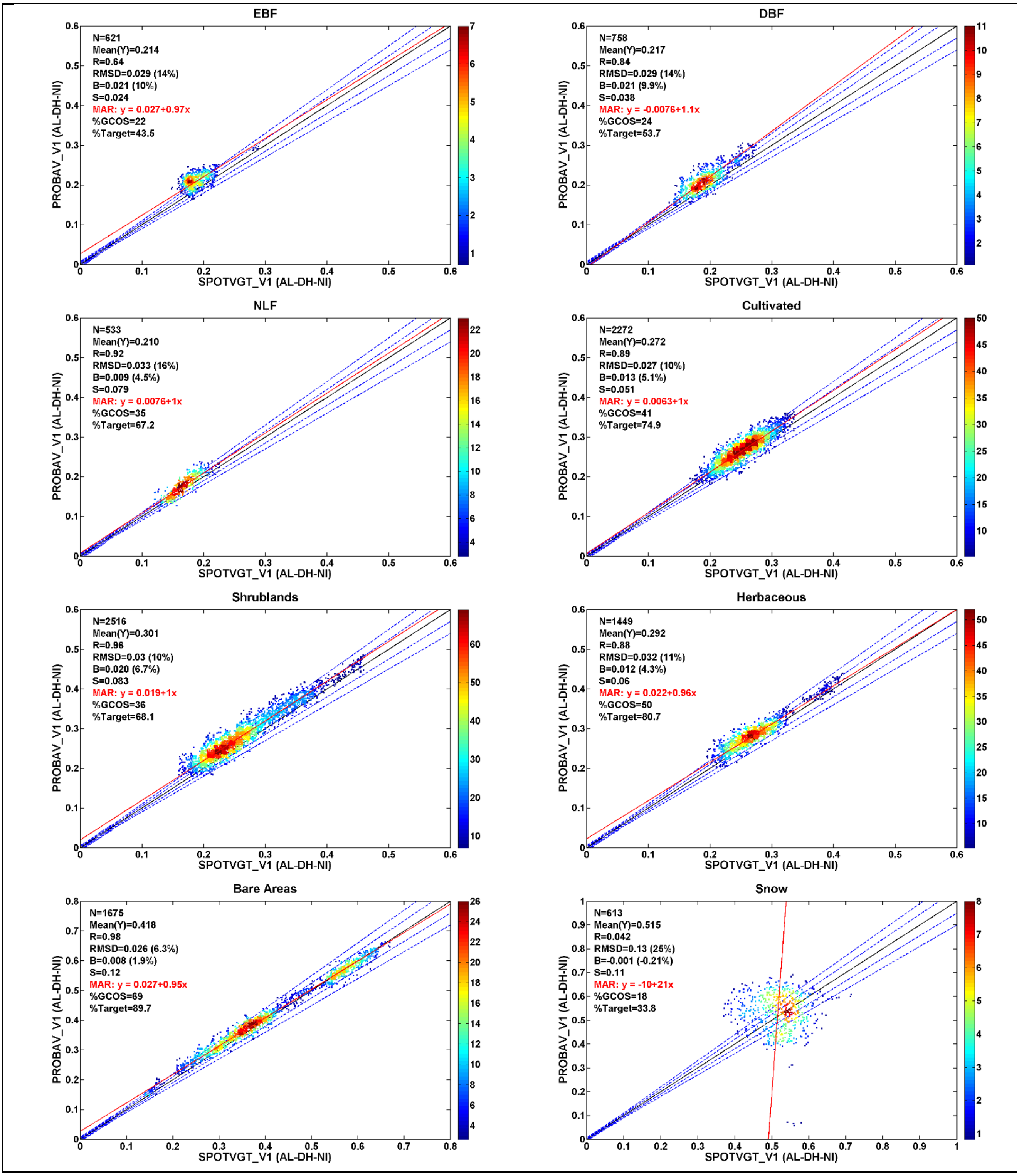


Figure 45: As in Figure 44 for AL-DH-NI.

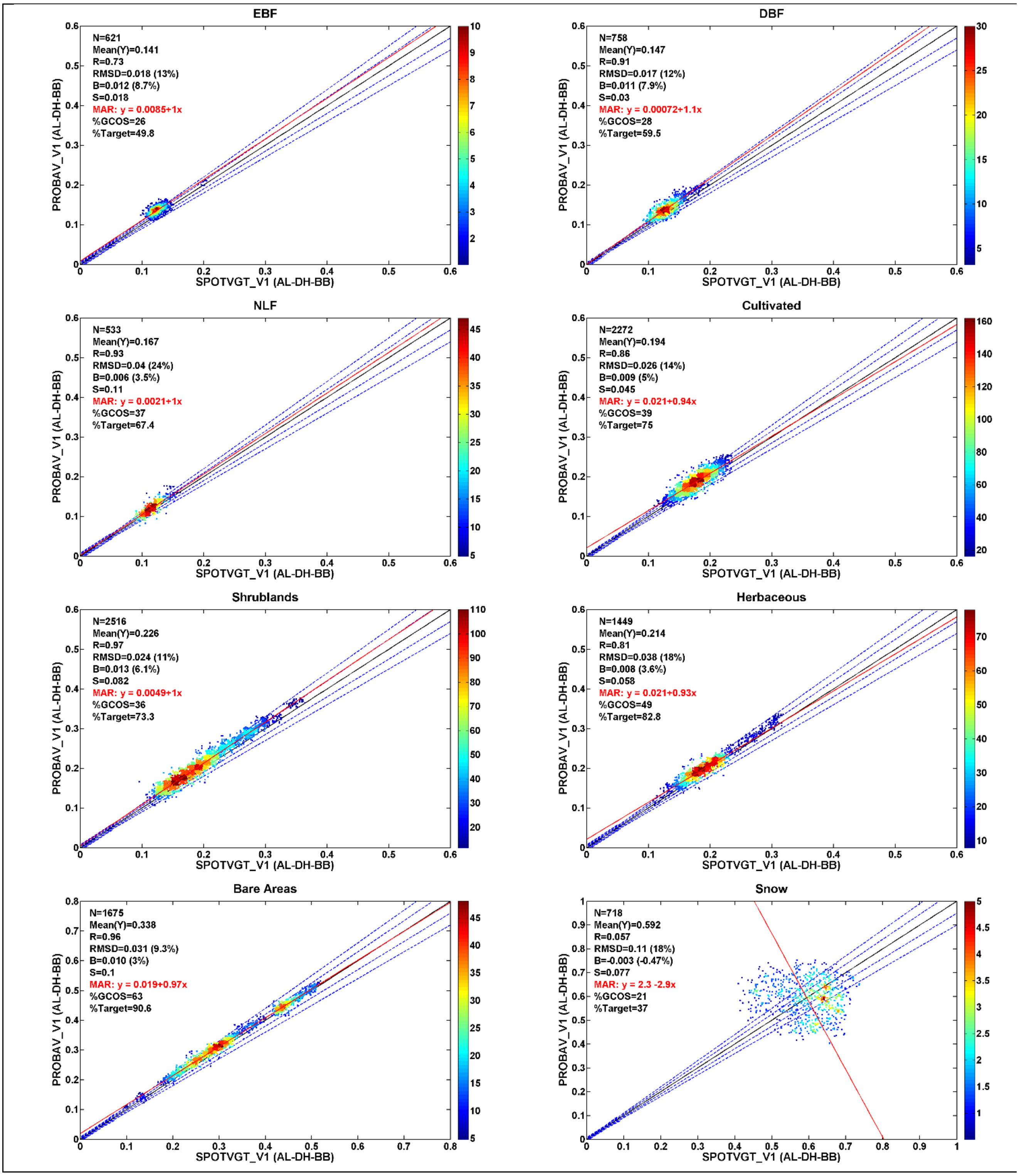


Figure 46: As in Figure 44 for AL-DH-BB.

For AL-DH-VI (Figure 44):

- Low bias (<3%, with random sign of differences) was found between PROBA-V and SPOT/VGT for all biome type, with the exception of the snow class (negative mean bias of 7.3%). For snow-free biomes, the largest bias (3%) was found for bare areas, confirming the global tendency observed in the map of differences (see ANNEX II)
- The main discrepancies are observed over snow pixels with low correlations (R=0.04) and negative slopes. Only 17% and 31% of pixels show optimal (CGOS) and target (CGLOPS optimal) level of consistency.
- Bare areas biome type showed the highest percentage of cases (88%) within the target requirements (CGLOPS optimal) (54% considering optimal GCOS level). For herbaceous and shrublands, more than 70% of pixels achieved target consistency (>40% optimal level). Worse agreement was found for forest sites and cultivated (~50% target, between 22% and 32% of cases showing optimal level). Note that for forest sites (low albedo values), the GCOS uncertainty requirements are more demanding.

For AL-DH-NI (Figure 45):

- Positive bias was found for all classes except for snow (almost no mean bias). Similar bias to the global tendency (~5%) was found for NLF, cultivated and herbaceous whereas larger bias of ~10% was found for EBF and DBF, and ~7% for shrublands. Remarkably good result in terms of mean bias (<2%) was found for bare areas.
- The main discrepancies are observed, again, over snow pixels. Even if almost no mean bias was found, large scattering was observed, with low correlations (R=0.04) and less than 20% and 34% of pixels showing optimal (GCOS) and target (CGLOPS optimal) level of consistency.
- Bare areas biome type showed the highest percentage of cases showing CGLOPS optimal consistency (~90%), followed by herbaceous (~81%). For the rest of biomes, lower percentage of cases showed CGLOPS optimal level, with percentages between 34% (snow) and 75% (cultivated).

Finally, for AL-DH-BB (Figure 46):

- As observed for AL-DH-NI, positive bias was found for all classes except for snow (almost no mean bias). Bias of ~8% was found for EBF and DBF, ~6% for shrublands, and <5% for the rest of classes, similar to that for the global assessment (~5%).
- The main discrepancies are observed, again, over snow pixels: large scattering, low correlations (R=0.06), and only 37% of pixels showing CGLOPS optimal level of consistency (21% considering GCOS requirements)
- Bare areas showed the best agreement, achieving CGLOPS optimal level of consistency in more than 90% of cases (63% considering GCOS requirements).
- For the rest of biomes, lower percentage of cases showed CGLOPS optimal level, ranging from 50% (EBF) to 83% (herbaceous). Typically, more than 35% of cases achieved the GCOS uncertainty level, except in EBF (26%) and DBF (28%).

4.6.3 Overall consistency between PROBA-V and MODIS C5 (2014 year)

The spatio-temporal consistency between PROBA-V SA V1.5 and MODIS C5 products was assessed over the LANDVAL network of sites during the whole 2014 year. For both products, pixels flagged as 'low quality' according to Table 9 were removed from the computation. Figure 47 shows the PROBA-V SA V1.5 versus MODIS C5 scatter-plots products for AL-DH-VI, AL-DH-NI and AL-DH-BB. The associated metrics for both black-sky and white-sky albedos are presented in Table 20.

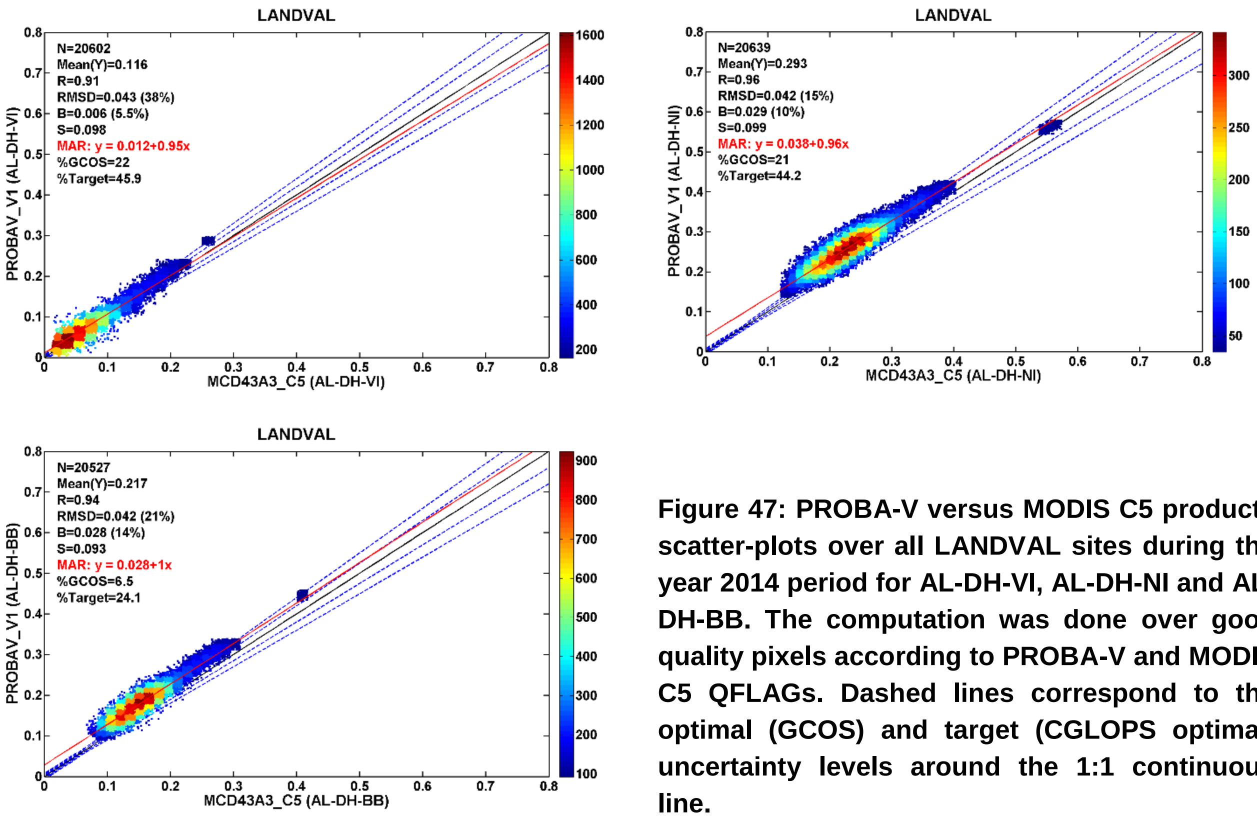


Figure 47: PROBA-V versus MODIS C5 products scatter-plots over all LANDVAL sites during the year 2014 period for AL-DH-VI, AL-DH-NI and AL-DH-BB. The computation was done over good quality pixels according to PROBA-V and MODIS C5 QFLAGs. Dashed lines correspond to the optimal (GCOS) and target (CGLOPS optimal) uncertainty levels around the 1:1 continuous line.

The main findings from Figure 47 and Table 20 are:

- For visible domain, positive bias (PROBA-V > MODIS) of ~5% was found, with more than 45% of pixels within the CGLOPS optimal uncertainty requirements (>20% considering GCOS requirements). Optimal linear regression relationships from the MAR were found (offset ~0 and slope ~1). In terms of RMSD, discrepancies of around 0.04 were found (36 and 38% for AL-DH-VI and AL-BH-VI).
- For the near infrared, positive bias (PROBA-V >MODIS) of ~10% was found, and RMSD of ~15%.Around 20% of retrievals showed optimal (GCOS) level of consistency (44.2% and

40.6% for AL-DH-NI and AL-BH-NI considering predefined target level, equivalent CGLOPS optimal requirement.

- The worse performance was found for the total spectrum, with large positive bias of ~0.03 (~15%) and RMSD of 0.04 (21%). 42.1% and 20.8% AL-DH-BB and AL-BH-BB pixels achieved CGLOPS optimal level of consistency (less than 7% considering GCOS requirements).
- Note that for NIR and for the total spectrum, the MAR relationships showed slopes ~1 and offsets very similar to the mean bias, which indicates the systematic positive bias between both products.
- Remarkably high correlations (R>0.9) were found for both black-sky and white-sky albedos in all spectral domains.
- Part of these discrepancies can be explained due to the different broadband ranges (see section 3.2.3).

Table 20: Performance statistics of PROBA-V versus MODIS C5 products over all LANDVAL sites during the 2014 year. The computation was done over good quality pixels according to PROBA-V and MODIS C5 QFLAGs.

	PROBA-V vs MODIS C5 (2014)					
	AL-DH-VI	AL-DH-NI	AL-DH-BB	AL-BH-VI	AL-BH-NI	AL-BH-BB
Correlation	0.91	0.96	0.94	0.91	0.95	0.94
Bias	0.006 (5.5%)	0.029 (10%)	0.028 (14%)	0.006 (4.8%)	0.034 (11%)	0.031 (15%)
RMSD	0.043 (38%)	0.042 (15%)	0.042 (21%)	0.043 (36%)	0.047 (16%)	0.046 (21%)
Offset	0.012	0.038	0.028	0.009	0.035	0.027
Slope	0.95	0.96	1	0.97	1	1
%optimal (GCOS)	22	21	6.5	23	19	6.8
%target (CGLOPS optimal)	45.9	44.2	24.1	45.5	40.6	20.8

- **Box-plot of uncertainties per bin**

Figure 48, Figure 49 and Figure 50 show the box-plots of the discrepancies (bias and RMSD) between PROBA-V SA V1.5 and MODIS C5 AL-DH-VI, AL-DH-NI and AL-BH-BB products per range of values during the 2014 year, computed over LANDVAL network of sites. Note that the QFLAG of PROBA-V was not used in order to increase the sampling of snow pixels (highest albedo values). The range value was computed as the average between both products, and the percentage of pixels within the predefined optimal (GCOS) and target (equivalent to CGLOPS optimal level) uncertainty levels (Figure 2, Table 4) was presented for each range.

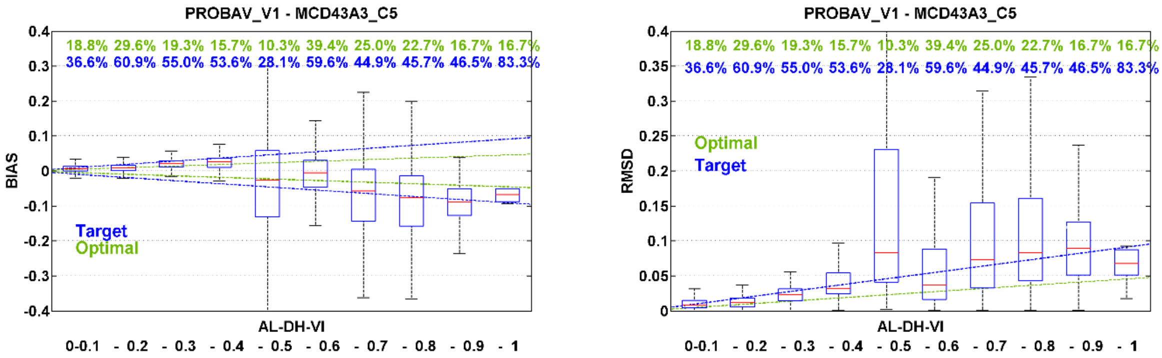


Figure 48: Box-plots of uncertainty statistics between PROBA-V SA V1.5 and MODIS C5 products (Bias: left side, RMSD: right side) per bin for AL-DH-VI during the 2014 year. Red bars indicate median values, blue boxes stretch from the 25th percentile to the 75th percentile of the data and whiskers include 99.3% of the coverage data (±2.7 σ). Outliers are not displayed. Green and blue lines correspond to optimal (GCOS) and target (CGLOPS optimal) uncertainty levels, and percentage of pixels within these levels are presented for each bin.

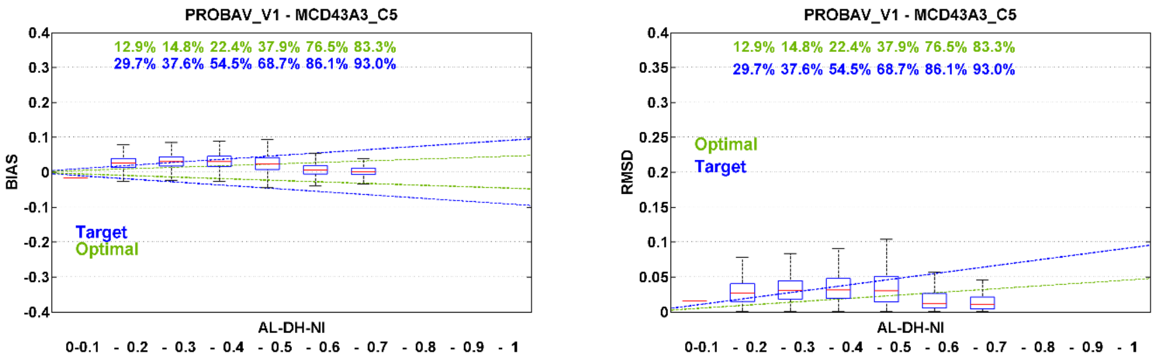


Figure 49: As in Figure 48 for AL-DH-NI.

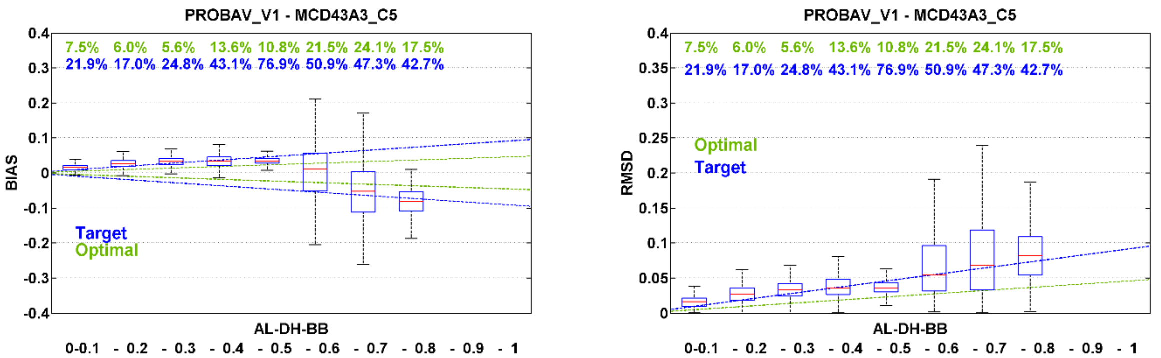


Figure 50: As in Figure 48 for AL-DH-BB.

For the visible domain (Figure 48):

- Positive bias (PROBA-V > MODIS) was found for albedo values lower than 0.4 whereas the opposite trend was found from albedos higher than 0.4. Median bias typically between the optimal and target predefined level was found. Larger dispersion was found for 0.4-0.5 and 0.6-0.8 levels.
- RMSD median values are typically within the CGLOPS optimal level for most of albedo ranges, and close to CGLOPS optimal level for 0.6-0.9 range. Larger discrepancies were found for the 0.4-0.5 range.
- Typically, between 37% and 83% of pixels are within the CGLOPS optimal level (20% and 30% within GCOS) of consistency except for the range of values between 0.4 and 0.5, where only 28% of pixels achieved CGLOPS optimal consistency (10% GCOS).
- Results are better for white-sky than for black-sky, both in terms of bias than in terms of RMSD.

For the near infrared (Figure 49):

- PROBA-V tends to provide higher values than MODIS for albedos lower than 0.5, and median bias close to zero was found for albedos higher than 0.5.
- As the albedo value increases, the percentage within the uncertainty requirements also increases. Percentages within the optimal (target) predefined level of consistency from 12.9% (29.7%) to 83.3% (93%) were found.
- Similar results were found between white-sky and black-sky, showing slight large bias and RMSD in white-sky.

For the shortwave (Figure 50):

- Large systematic positive bias was found for albedos up to 0.5, with median values out of CGLOPS optimal level for the lowest ranges (SA<0.3). Large scattering was found for the highest albedo values (SA>0.5), with typically negative bias over the highest albedo ranges (typically snow values).
- Less than 45% of pixels showed CGLOPS optimal agreement for the lowest albedo ranges (SA<0.4), whereas slight better results were found from 0.5 onwards (except for 0.7-0.8 range).
- Similar results were found between white-sky and black-sky, showing slight better results for the highest albedo ranges (0.6-0.8).

4.6.4 Analysis per biome type (PROBA-V versus MODIS C5)

Scatter-plots between PROBA-V SA V1.5 and MODIS C5 products were analyzed per biome type over LANDVAL sites during the 2014 year over good quality pixels according to the QFLAG of both products (see Table 9). Note that, because the QFLAG of PROBA-V was used to discard pixels flagged as 'low quality', most of the snow pixels were removed from the computation. Then, the statistics over specific snow conditions can be found over the snow class, where the QFLAG of PROBA-V was not considered in the computation. Figure 51, Figure 52 and Figure 53 show the scatter-plot for AL-DH-VI, AL-DH-NI and AL-DH-BB respectively. The scatter plots per biome type for white-sky albedos, as well as the analysis per continental region are included in the Digital Annex.

For AL-DH-VI (Figure 51):

- No systematic trend of the sign of the bias was found. Bias lower than 5% was found for most of the classes (NLF, shrublands, herbaceous), and slightly higher in bare areas (6%) and cultivated (8%). The main discrepancies in terms of mean bias were found for the biomes characterized by the lowest albedos (EBF and DBF, ~16%) and by the highest (snow, 11%).
- The main discrepancies are observed over snow pixels, with less than 30% of pixels showing CGLOPS optimal level of consistency, low correlations (R=0.002) and negative slope.
- Between 30% and 63% of pixels achieved the CGLOPS optimal level of consistency for all biome type.

For AL-DH-NI (Figure 52):

- Positive bias was found for all classes except for snow. Bias typically ~10% was found, with better results in bare areas (~5%) and worse in DBF (19%) and NLF (17%)
- The main discrepancies are observed over snow pixels: large scattering, low correlation (R=0.05) and negative slope.
- For bare areas, 72% of pixels achieved CGLOPS optimal consistency. For the rest of biome types, less than 50% of pixels achieved the CGLOPS optimal requirements level except for EBF (~56%).

Finally, for AL-DH-BB (Figure 53):

- As observed for AL-DH-NI, positive bias was found for all classes except for snow (negative mean bias of 7.3%). Large mean bias (~15-20%) was found for forest classes and cultivated, and slightly lower (13%-14%) in shrublands and herbaceous. Better results in terms of mean bias were found for bare areas, showing the best case (~10%)
- Less than 40% of pixels achieved CGLOPS optimal consistency (except for Bare Areas with 47.9%), showing worse results than for the visible and near infrared spectral domains.
- The main discrepancies are observed, again, over snow pixels in terms of scattering, low correlations (R=0.005) and MAR relationships. Discrepancies over snow targets could be explained by different factors, such as the difference in number of clear observations available during large temporal composites, the larger uncertainties in the BRDF models used for albedo computation, and the low SZA over northern latitudes which introduce additional uncertainties.

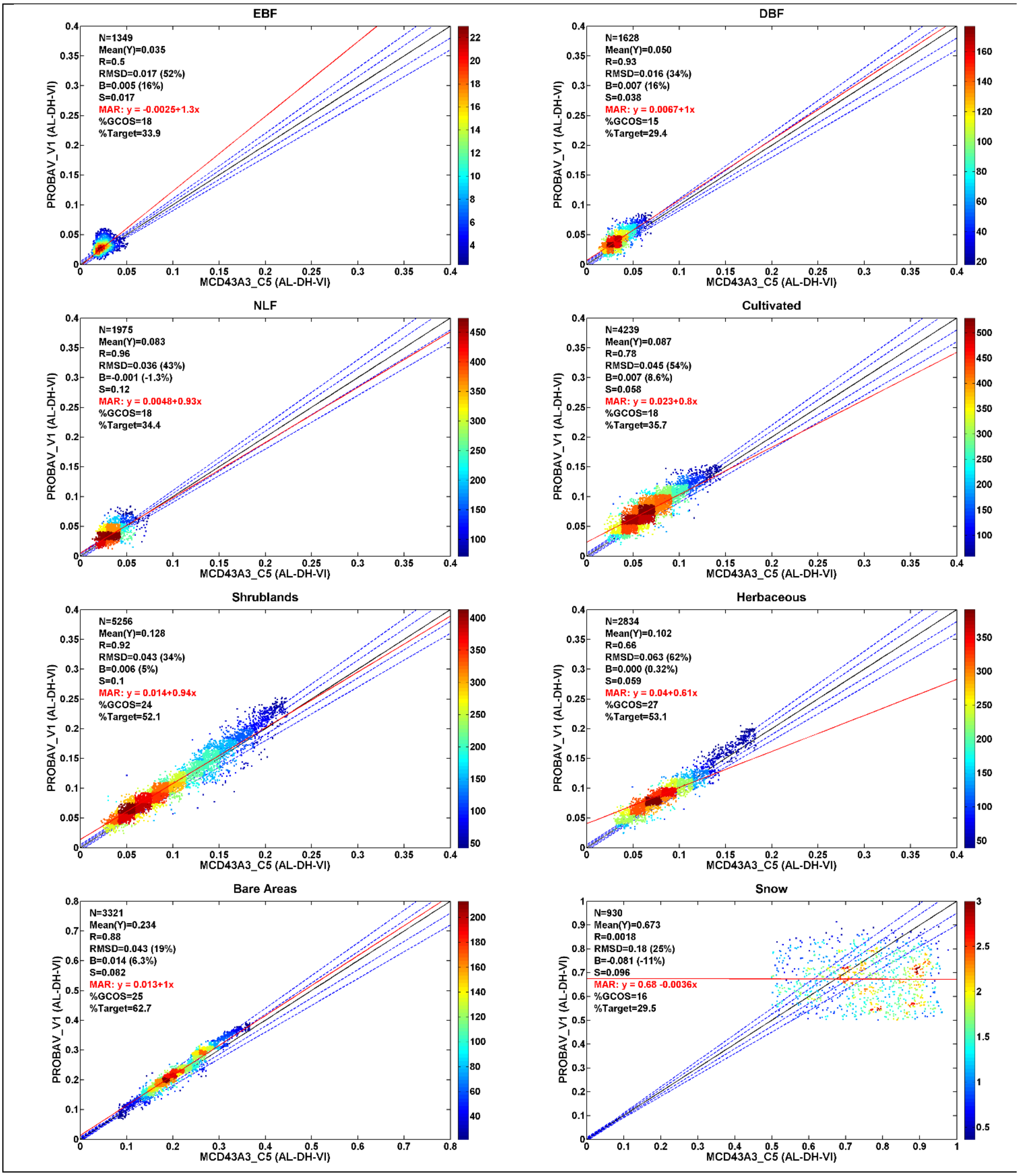


Figure 51: PROBA-V SA V1.5 versus MODIS C5 (AL-DH-VI) products scatter-plots over LANDVAL sites for the 2014 year for each land cover type. Dashed lines correspond to the optimal (GCOS) and target (CGLOPS optimal) uncertainty levels around the 1:1 continuous line.

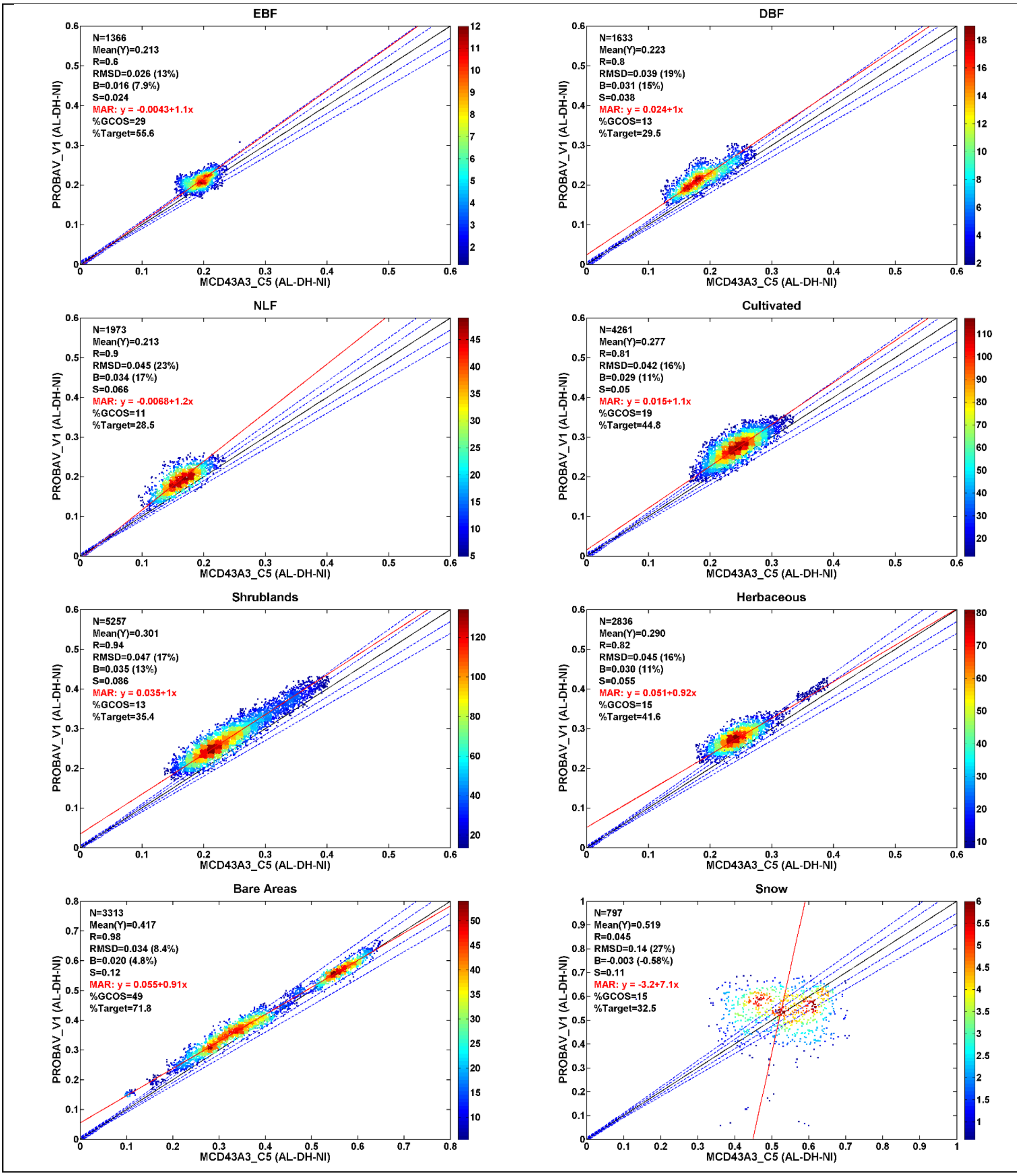


Figure 52: As in Figure 51 for AL-DH-NI.

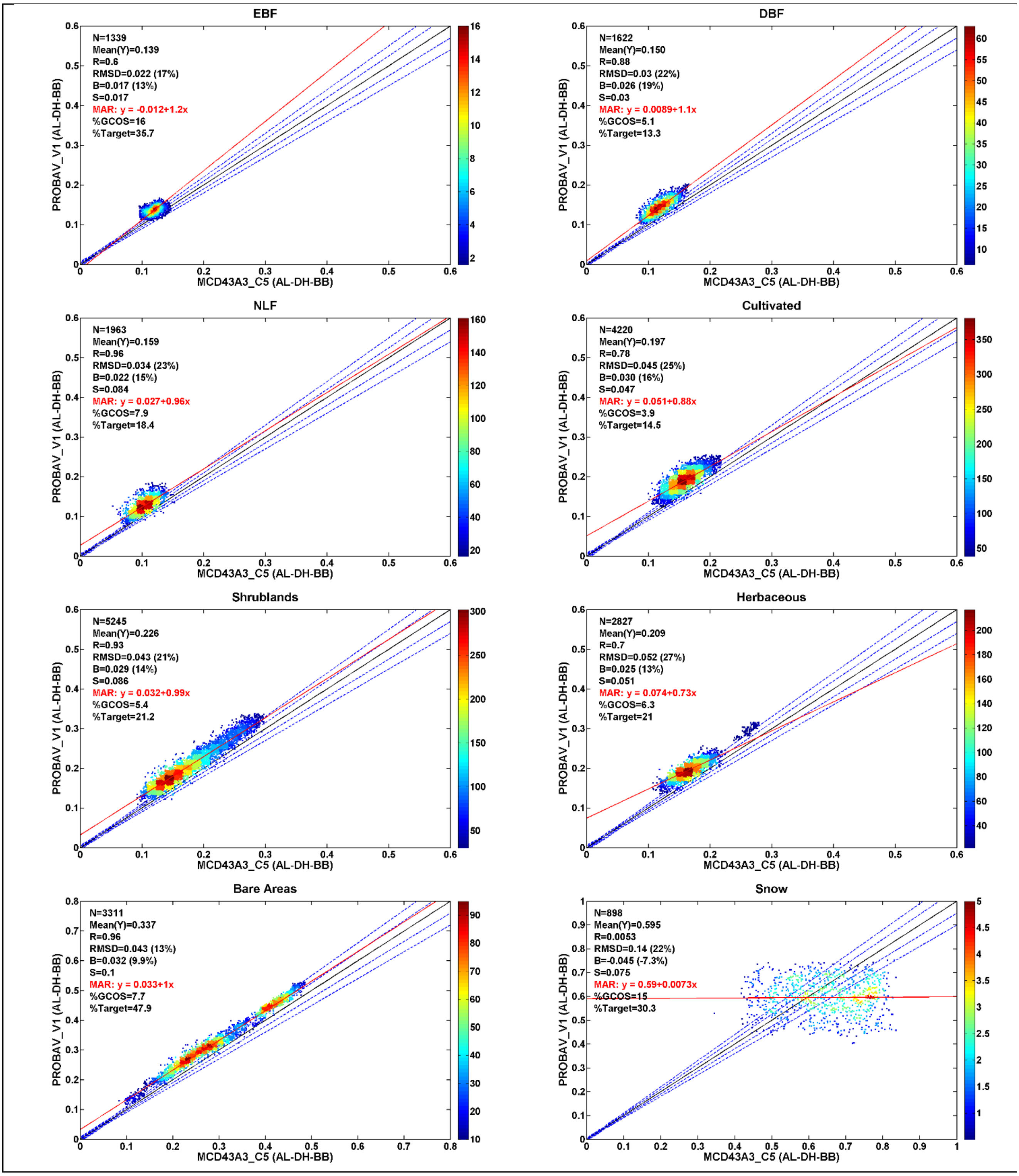


Figure 53: As in Figure 51 for AL-DH-BB.

4.7 ACCURACY ASSESSMENT

To investigate the accuracy of PROBA-V SA V1.5 (and MODIS C5 for benchmarking) satellite albedo products ("blue-sky" albedo), scatter plots versus field measurements were produced for the whole 2014 year over 17 SURFRAD and EFDC sites of different vegetation types. This exercise was performed at 1-km resolution, 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. This analysis was carried out over good quality PROBA-V and MODIS C5 pixels according to QFLAGs (Table 9) and 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, in case of PROBA-V, pixels flagged as snow in the Quality Flag were also rejected from the computation.

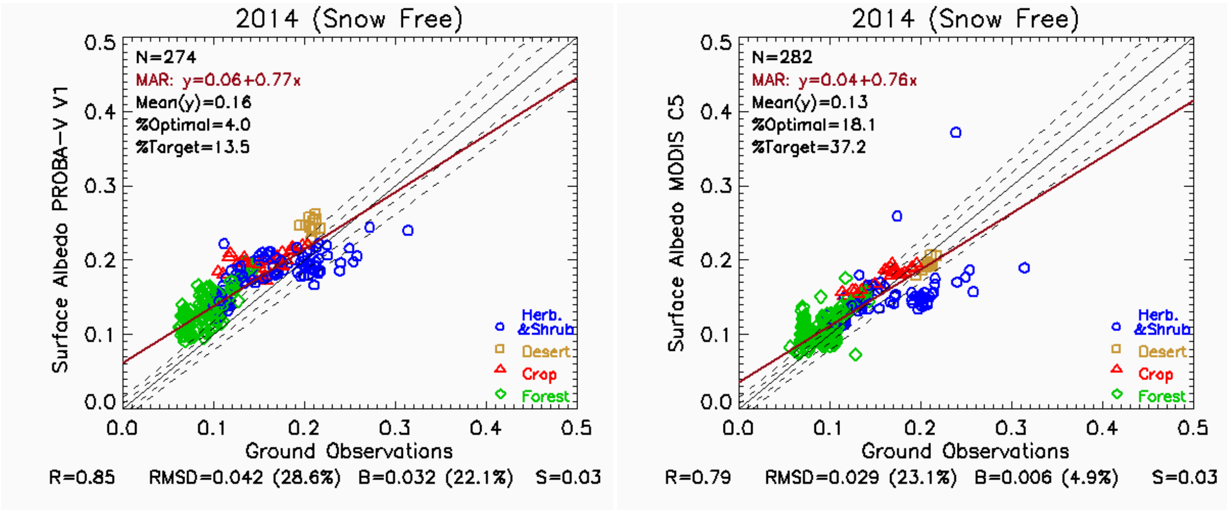


Figure 54: Accuracy Assessment of PROBA-V SA V1.5 Collection 1km (left) and MODIS MCD43A3 C5 (right) blue-sky albedo satellite products versus ground values coming from SURFRAD and EFDC stations during the 2014 year for Snow Free conditions. Continuous black line corresponds to 1:1 line and dashed lines to optimal (GCOS uncertainty requirement) and target (CGLOPS optimal requirement)levels. Red line corresponds to the Major Axis Regression (MAR).

The main conclusions from scatter-plots (Figure 54) and associated metrics (Table 21) are:

- Overall accuracy of RMSD=0.042 was found for PROBA-V SA V1.5 products, showing worse results in terms of RMSD than MODIS C5 (RMSD=0.029).MODIS C5 results are also consistent with previous validation exercises over SURFRAD sites (Jin, Y. et al., 2003; Liu, J. et al., 2009).

- Positive bias of 0.032 (22.1%) of PROBA-V SA Collection 1km was found. This positive bias was found for albedo values up to 0.2. From 0.2 onwards, PROBA-V tends to overestimate measurements over desertic sites, and to underestimate shrublands and herbaceous measurements. MODIS C5 showed improved results in terms of bias, showing low positive bias of 0.006 (4.9%).
- PROBA-V overall accuracy (RMSD=0.042) and mean bias (0.032) are worse to that found for SPOT/VGT SA V1.4 during the validation exercise [GIOGL1_VR_SA1km-V1] over snow-free conditions (RMSD=0.03, bias=0.005). It should be noted that different sampling was used in this study compared to the SPOT/VGT validation exercise (different sites and dates).
- 13.5% and 41.6% of PROBA-V pixels achieved the CGLOPS optimal and target requirements. Higher percentage of MODIS C5 pixels achieved CGLOPS optimal and target requirement levels (37.2% and 78.4% respectively).
- Only 4% of 274 PROBA-V samples achieved the GCOS uncertainty requirements. In spite of the good results of MODIS C5 in terms of RMSD and bias, the low percentage of pixels within GCOS requirements (18.1%) indicates the difficulties to achieve GCOS requirements. CGLOPS requirements seems to be more realistic.

Table 21: Relevant statistics of the Accuracy Assessment of PROBA-V SA V1.5 Collection 1km (left) and MODIS MCD43A3 C5 (right) blue-sky albedo satellite products versus ground values coming from 17 SURFRAD and EFDC stations during the 2014 year for Snow Free conditions.

	SURFRAD & EFDC SITES (2014)	
	PROBA-V SA V1.5	MCD43A3 C5
N	274	282
Correlation (R)	0.85	0.79
Bias	0.032 (22.1%)	0.006 (4.9%)
RMSD	0.042 (28.6%)	0.029 (23.1%)
Offset (MAR)	0.06	0.04
Slope (MAR)	0.77	0.76
%optimal (GCOS)	4	18.1
%target (CGLOPS optimal)	13.5	37.2
%threshold (CGLOPS target)	41.6	78.4

5 SUMMARY AND CONCLUSIONS

The quality assessment of PROBA-V SA V1.5 product was conducted following the validation procedure described in the Copernicus Global Land Service Validation Plan [CGLOPS1_SVP]. The analysis is mainly focused on the consistency of PROBA-V and SPOT/VGT SA V1.5 products for the overlap period (December 2013 –May 2014). Moreover, MODIS C5 products were considered for the statistical inter-comparison during whole 2014, as well as to investigate the consistency of the temporal trajectories. The following main criteria were assessed: completeness, spatial consistency, temporal consistency, smoothness and the overall assessment of the spatio-temporal consistency with similar products and accuracy. The accuracy was quantified by direct comparison with ground measurements coming from 17 SURFRAD and EFDC stations over homogeneous sites at 1-km^2. Main results and conclusions are summarized below:

Product Completeness

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

Spatial Consistency and Product Content

- Global maps and maps over sub-continental regions of PROBA-V SA V1.5 products showed reliable distributions for both black-sky and white-sky albedos in all spectral domains, without finding spatial artifacts. Ancillary layers (errors, NMOD and QFLAG) showed reliable and consistent values. However, a sharp latitudinal transition over northern hemisphere (around ~50º) was observed during December 2013, January 2014, February 2014 and December 2014 due to some limitation on cloud screening of PROBA-V input data.
- In terms of bias, global maps of differences between PROBA-V and SPOT/VGT SA V1.5 products showed systematic positive bias (PROBA-V > SPOT/VGT) for NIR and shortwave

around the whole globe except for snow (random sign). For visible domain, no systematic bias was found, with the exception of desertic areas (positive bias).

- Global distributions of residuals showed typically around 36% of AL-DH-VI residuals showing optimal consistency (60% considering the target uncertainty level). For AL-DH-NI and AL-DH-BB ~50% of pixels showed optimal consistency (~70-75% target). Slightly lower percentage of optimal cases was found for white-sky albedos.
- Poor consistency pixels (achieved only in ~4% for AL-DH-VI and AL-DH-BB and in ~7% for AL-DH-NI) are randomly distributed around the globe, with the exception of arid and semi-arid regions, where optimal spatial consistency was found.
- PROBA-V showed positive spatial autocorrelation over the six LANDVAL homogeneous sites located over EBF, DBF, NLF, Herbaceous, Shrubs and desertic areas of interest. However, PROBA-V tends to provide generally lower spatial correlation (MI) than SPOT/VGT and MODIS C5, and higher CV.

Temporal Consistency

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

Intra-Annual Precision (smoothness)

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

Overall Spatio-Temporal Consistency

- PROBA-V versus SPOT/VGT:
  - Scatter-plots and uncertainty statistics between PROBA-V and SPOT/VGT SA V1.5 (best quality pixels) products over LANDVAL sites during the overlap period show good consistency for all spectral bands, with correlations higher than 0.93 for all spectral domains. Slight positive bias of ~5% was found for NIR and shortwave, and almost no mean bias for visible.
  - 39%, 43% and 42% (67%, 73%, and 75%) of pixels showed optimal (target) level of consistency between PROBA-V and SPOT/VGT for AL-DH-VI, AL-DH-NI and AL-DH-BB, with worse results (~3-5%) for white sky albedos.
  - Per value range, median bias close to zero was found for all albedo range in visible domain. For NIR and shortwave, PROBA-V tends to provide higher albedo values than SPOT/VGT for all ranges except for snow (highest ranges).
  - For visible domain, low bias (<3%, with random sign) was found for all biome type with larger negative bias for snow (-7.3%). Percentage of pixels within the optimal (GCOS) level ranges from 17% (worse case, snow class) to 88% (best case, bare areas).
  - For NIR and shortwave, systematic positive bias (<10% for NIR, and <8% for shortwave) was found for all classes except for snow, where the main discrepancies were found. Percentage of pixels within the optimal (GCOS) level ranges from 18% in NIR and 21% in shortwave (worse case, snow class) to 69% and 63% (best case, bare areas).
- PROBA-V versus MODIS C5:
  - The comparison between PROBA-V V1.5 and MODIS C5 SA for the whole 2014 year showed higher correlations(R>0.91) regardless the spectral domain. Positive biases of ~5%, ~10% and ~15% were found for visible, NIR and total spectrum.
  - The percentages of pixels between the optimal/target levels were 22%/46%, 21%/44%, and 7%/24% for AL-DH-VI, AL-DH-NI and AL-DH-BB, showing similar values for AL-BH retrievals.
  - Per range value, for visible domain PROBA-V provides higher values than MODIS for SA<0.4, and the opposite trend was found for SA>0.4. For NIR, median positive bias was found for SA<0.5, and median positive bias ~0 for SA>0.5. For the total spectrum, large positive bias was found, positive for SA<0.5 and negative for SA>0.5.

- Per biome type, no systematic trend of sign of the bias was found for visible domain, with typically between 15% and 30% of pixels achieving the optimal for all biome type. For NIR, positive bias (typically <15%) was found for all classes except for snow (-0.6%).The percentage of pixels showing optimal consistency in NIR domain was less than 30% for all classes, with significant better results in bare areas (49%). Similar results were found for shortwave than for NIR, but showing large discrepancies (large bias and less than 16% of pixels achieving optimal consistency for all classes).

Accuracy Assessment

- The comparison of PROBA-V SA V1.5 with field data for 17 SURFRAD and EFDC homogeneous sites shows RMSD of 0.042 for the 2014 year, showing improved results in MODIS C5 (0.029). PROBA-V provides systematic overestimation (mean bias of 0.032, 22.1%), whereas MODIS C5 provides low bias (0.006, 4.9%).
- 13.5% and 41.6% of PROBA-V pixels achieved the CGLOPS optimal and target requirements (37.2% and 78.4% in case of MODIS C5).
- Very low percentage of PROBA-V pixels within the GCOS requirements was found (4% of 274 samples). In case of MODIS C5, 18.1% of pixels achieved the GCOS requirements.

Concluding remarks

The PROBA-V SA V1.5 products have reached a good quality in most of the criteria evaluated, reaching the validated stage 1 at the CEOS LPV hierarchy. However, some drawbacks were identified that users must take carefully into account when using the products:

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

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 retrievals over snow targets. Then, the use of the QFLAG is not recommended for snow applications.

The main results of each quality criteria of this study are summarized in Table 22.

Table 22: Summary of PROBA-V SA V1.5 product evaluation. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

QA Criteria	Performance	Comments
Product Completeness	**-**	Main limitations over Northern latitudes in wintertime and Equatorial areas. Similar results than SPOT/VGT products, showing larger percentage of missing data.
Spatial Consistency	**±**	Reliable and consistent values over the whole globe, without observing spatial artefacts with the exception of a sharp latitudinal transition ~50º during winter season. Global distributions showed systematic positive bias (PROBA-V > SPOT/VGT) for NIR and BB, and bias 0 for VI. Global distributions of residuals showed ~36% of cases within the optimal level for VI, and 50% for NI and BB. Good repeatability over well-known homogenous areas. Positive spatial autocorrelation (MI) and low spatial variability (CV). MI lower than both references (SPOT/VGT and MODIS C5), and higher CV.
Temporal Consistency	**+**	Reliable temporal variations for most of the cases compared with satellite reference products and ground observations. Cross-correlation between PROBA-V and SPOT/VGT greater than 0.7 in more than 50% (VI and BB) and 40% (NI) of cases except in EBF and snow. Worse results compared to MODIS C5.
Intra-Annual Precision	**+**	Similar smoothness than both references (SPOT/VGT and MODIS C5), showing slightly higher δ values in NI.
Overall Spatio-Temporal Consistency	**±**	PROBA-V vs SPOT/VGT shows high correlation (R>0.93) and low scattering, with almost no mean bias in VI and systematic positive mean bias of ~5% in NI and BB (except in snow). 39%, 43% and 42% (67%, 73%, and 75%) of pixels showed optimal (target level) for VI, NI and BB. Comparison of PROBA-V and SPOT/VGT per biome type showed low bias (<3%, random sign) for VI, and positive bias for NI and BB in all biome types. The exception was the snow class, with negative bias. Good performance as compared with MODIS C5 in terms of correlations (R>0.91), with relative mean bias of ~5%, ~10% and ~15% for VI, NI and BB, during the whole 2014 year. Percentage of pixels between the optimal (target) levels: 22% (46%), 21% (44%), and 7% (24%) for VI, NI and BB. Comparison of PROBA-V and MODIS C5 per biome type showed no systematic trend of the sign of bias for VI, and positive bias for NI and BB for all classes except for snow (negative).
Accuracy Assessment	**-**	PROBA-V: N=274; B=0.032 (22.1%); RMSD=0.042; Snow free conditions. 13.5% and 41.6% of pixels within CGLOPS optimal and target levels. 4% of pixels within GCOS. 4%, 13.5% and 32.5 of pixels within WMO goal, breakthrough and threshold levels. Improved results for MODIS C5 using the same sampling: B=0.006 (4.9%); RMSD= 0.029; 37.2% and 78.4% of pixels within CGLOPS optimal and target levels. 18.1% of pixels within GCOS. 18.1%, 37.2% and 66.7% of pixels within WMO goal, breakthrough and threshold levels.

Since the final objective of the quality assessment analysis is to verify how much the products are compliant with the users' requirements (see Chapter 2), we set-up a compliance matrix (Table 23). The last column states in how far these requirements are met by PROBA-V surface albedo products.

Table 23: Compliance matrix of CGLOPS, GCOS and WMO requirements for PROBA-V Surface albedo V1.5 product.

Requirement	Source	Objective	Match
Horizontal Resolution	GCOS	200/500m	No (1km)
	WMO High resolution NWP	Goal (0.5km) Breakthrough (4km) Threshold (10km)	Breakthrough (1km < 4km)
	WMO Nowcasting/VSRF	Goal (1km) Breakthrough (5km) Threshold (10km)	Goal
Temporal Resolution	GCOS	Daily	No, PROBA-V SA temporal resolution=10 days
Observing Cycle	WMO High resolution NWP	Goal (1h) Breakthrough (3h) Threshold (12h)	No, PROBA-V SA observing cycle = 30 days
	WMO Nowcasting/VSRF	Goal (1d) Breakthrough (3d) Threshold (90d)	Threshold (30 days)
Timeliness	WMO High resolution NWP	Goal (1h) Breakthrough (3h) Threshold (12h)	No, CGLOPS product timeliness = 3 days
	WMO Nowcasting/VSRF	Goal (0.5d) Breakthrough (1d) Threshold (3d)	Threshold (3 days)
Accuracy	GCOS	Max(5%; 0.0025)	4% of pixels within GCOS No in terms of RMDS, RMSD=28% (snow-free pixels)
	WMO High resolution NWP WMO Nowcasting/VSRF	Goal (5%) Breakthrough (10%) Threshold (20%)	4%, 13.5% and 32.5 of pixels within WMO goal, breakthrough and threshold levels. No in terms of RMSE (28%). Close to threshold in terms of mean bias over snow-free pixels (Bias=22%)
	CGLOPS	Optimal: 5% Target: - 0.03 for SA<0.15 - 20% for SA>0.15	13.5% and 41.6% of pixels within CGLOPS optimal and target levels. No in terms of RMSE (28%). Close to target in terms of mean bias over snow-free pixels (Bias=22%)

6 REFERENCES

Baret, F., Morissette, J.T., Fernandes, R.A., Champeaux, J.L., Myneni, R.B., Chen, J., Plummer, S., Weiss, M., Bacour, C., Garrigues, S., Nickeson, J.E., 2006. Evaluation of the representativeness of networks of sites for the global validation and intercomparison of land biophysical products: Proposition of the CEOS-BELMANIP. IEEE Trans. Geosci. Remote Sens. 44, 1794–1802. doi:10.1109/TGRS.2006.876030

Bartholome, E., Belward, A., 2005. GLC2000: a new approach to global land cover mapping from Earth observation data. Int. J. Remote Sens. 26, 1959–1977. doi:10.1080/01431160412331291297

Camacho, F., Cernicharo, J., Lacaze, R., Baret, F., Weiss, M., 2013. GEOV1: LAI, FAPAR essential climate variables and FCOVER global time series capitalizing over existing products. Part 2: Validation and intercomparison with reference products. Remote Sens. Environ. 137, 310–329. doi:10.1016/j.rse.2013.02.030

Carrer, D., Roujean, J., Meurey, C., 2010. Comparing Operational MSG / SEVIRI Land Surface Albedo Products From Land SAF With Ground Measurements and MODIS. IEEE Trans. Geosci. Remote Sens. 48, 1714–1728. doi:10.1109/TGRS.2009.2034530

Cescatti, A., Marcolla, B., Vannan, S.K.S., Pan, J.Y., Roman, M.O., Yang, X., Ciais, P., Cook, R.B., Law, B.E., Matteucci, G., Migliavacca, M., Moors, E., Richardson, A.D., Seufert, G., Schaaf, C.B. (2012). Intercomparison of MODIS albedo retrievals and in situ measurements across the global FLUXNET network. Remote Sens. Environ. 121, 323-334.

Fell, F., Bennartz, R., Loew, A., 2015. Validation of the EUMETSAT Geostationary Surface Albedo Climate Data Record -2- (ALBEDOVAL-2).

Fernandes, R., Plummer, S.E., Nightingale, J., Baret, F., Camacho, F., Fang, H., Garrigues, S., Gobron, N., Lang, M., Lacaze, R., LeBlanc, S., Meroni, M., Martinez, B., Nilson, T., Pinty, B., Pisek, J., Sonnentag, O., Verger, A., Welles, J., Weiss, M., Widlowski, J.-L., Schaepman-Strub, G., Roman, M., Nicheson, J., 2014. Global Leaf Area Index Product Validation Good Practices. CEOS Working Group on Calibration and Validation - Land Product Validation Sub-Group. Version 2.0. Public version made available on LPV website. doi:10.5067/doc/ceoswgcv/lpv/lai.002

Garrigues, S., Lacaze, R., Baret, F., Morisette, J.T., Weiss, M., Nickeson, J.E., Fernandes, R., Plummer, S., Shabanov, N. V., Myneni, R.B., Knyazikhin, Y., Yang, W., 2008. Validation and intercomparison of global Leaf Area Index products derived from remote sensing data. J. Geophys. Res. Biogeosciences 113. doi:10.1029/2007JG000635

GCOS-154 (2011). Systematic Observation Requirements for Satellite-based Products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC - 2011 Update, WMO, Geneva, Switzerland.

GCOS-200 (2016). Systematic Observation Requirements for Satellite-based Products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC - 2016 Update, WMO, Guayaquil, Ecuador.

Harper, W. V., 2014. Reduced Major Axis regression: teaching alternatives to Least Squares. Proc. Ninth Int. Conf. Teach. Stat. 1–4. doi:10.1016/B978-0-12-420228-3.00013-0

Jin, Y., C. B. Schaaf, C. E. Woodcock, F. Gao, X. Li, A. H. Strahler, W. Lucht, and S. Liang, (2003). Consistency of MODIS surface bidirectional reflectance distribution function and albedo retrievals, 2. Validation. Journal of Geophysical Research, vol. 108, no. D5, 4159.

Lewis, P., and M. J. Barnsley, (1994). Influence of the sky radiance distribution on various formulations of the Earth surface albedo. Paper presented at International Symposium on Physical Measurements and Signatures in Remote Sensing, Int, Soc. for Photogramm. andTemote Sens., Val d'Isere, France.

Liu,J., C. Schaaf, A. Strahler, Z. Jiao, Y. Shuai, Q. Zhang, M. Roman, J. A. Augustine and E. G. Dutton (2009). Validation of Moderate Resolution Imaging Spectroradiometer (MODIS) albedo retrieval algorithm: Dependence of albedo on solar zenith angle. Journal of Geophysical Research, Vol. 114, D01106, doi:10.1029/2008JD009969.

Loew, A., Bennartz, R., Fell, F., Lattanzio, A., Doutriaux-Boucher, M., Schulz, J., 2016. A database of global reference sites to support validation of satellite surface albedo datasets (SAVS 1.0). Earth Syst. Sci. Data 8, 425–438. doi:10.5194/essd-8-425-2016

Lucht, W., Schaaf, C.B., Strahler, A.H., 2000. An Algorithm for the Retrieval of Albedo from Space Using Semiempirical BRDF Models. IEEE Trans. Geosci. Remote Sens. 38, 977–998.

Maignan, F., Breon, F.-M., Lacaze, R., 2004. Bidirectional reflectance of Earth targets : Evaluation of analytical models using a large set of spaceborne measurements with emphasis on the Hot Spot. Remote Sens. Environ. 90, 210–220. doi:10.1016/j.rse.2003.12.006

Moran, P., 1948. The Interpretation of Statistical Maps. J. R. Stat. Soc. Ser. B 10, 243–251.

Román, M.O., Schaaf, C.B., Woodcock, C.E., Strahler, A.H., Yang, X., Braswell, R.H., Curtis, P.S., Davis, K.J., Dragoni, D., Goulden, M.L., Gu, L., Hollinger, D.Y., Kolb, T.E., Meyers, T.P., Munger, J.W., Privette, J.L., Richardson, A.D., Wilson, T.B., Wofsy, S.C., 2009. Remote Sensing of Environment The MODIS (Collection V005) BRDF / albedo product : Assessment of spatial representativeness over forested landscapes. Remote Sens. Environ. 113, 2476–2498. doi:10.1016/j.rse.2009.07.009

Román, M. O., Schaaf, C. B., Lewis, P., Gao, F., Anderson, G. P., Privette, J. L., et al. (2010). Assessing the coupling between surface albedo derived from MODIS and the fraction of diffuse skylight over spatially-characterized landscapes. Remote Sensing of Environment, 114, 738– 760.

Roujean, J.-L., Leroy, M., Deschamps., P.-Y., 1992. A bidirectional reflectance model of the Earth's surface for the correction of remote sensing data. J. Geophys. Res. 97, 20455–20468.

Salomon, J.G., Schaaf, C.B., Strahler, A.H., Measurements, A.S.A., 2006. Validation of the MODIS Bidirectional Reflectance Distribution Function and Albedo Retrievals Using Combined Observations From the Aqua and Terra Platforms. IEEE Trans. Geosci. Remote Sens. 44, 1555–1565.

Sánchez-Zapero, J., de la Madrid, L., Camacho, F., 2017. SALVAL: a semi-automatic surface albedo validation tool. Proceeding of the V International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS). Valencia (Spain), 18-22 September, 2017.

Schaaf, C.B., Gao, F., Strahler, A.H., Lucht, W., Li, X., Tsang, T., Strugnell, N.C., Zhang, X., Jin, Y., Muller, J.P., Lewis, P., Barnsley, M., Hobson, P., Disney, M., Roberts, G., Dunderdale, M., Doll, C., D'Entremont, R.P., Hu, B., Liang, S., Privette, J.L., Roy, D., 2002. First operational BRDF, albedo nadir reflectance products from MODIS. Remote Sens. Environ. 83, 135–148. doi:10.1016/S0034-4257(02)00091-3

Schaaf, C.B., Liu, J., Gao, F., Strahler, A.H., 2011. MODIS Albedo and Reflectance Anisotropy Products from Aqua and Terra. Remote Sens. Digit. Image Process. Ser. 1–15.

Shuai, Y., Schaaf, C.B., Strahler, A.H., Liu, J., Jiao, Z., 2008. Quality assessment of BRDF / albedo retrievals in MODIS operational system. Geophys. Res. Lett. 35. doi:10.1029/2007GL032568

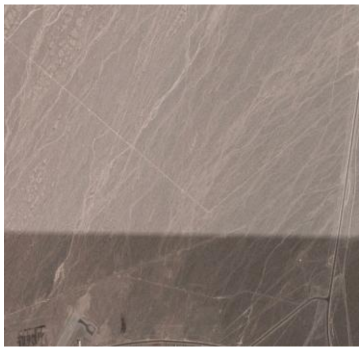
Toté, C., E. Swinnen, S. Sterckx, D. Clarijs, C. Quang and R. Maes, 2017. Evaluation of the SPOT/VEGETATION Collection 3 reprocessed dataset: surface reflectances and NDVI. Remote Sensing of Environment, 201, 219-233. http://dx.doi.org/10.1016/j.rse.2017.09.010

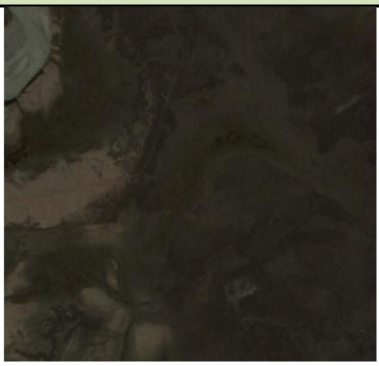
Wanner, W., Strahler, A.H., Hu, B., Lewis, P., Li, X., Barker, C.L., 1997. Global retrieval of bidirectional reflectance and albedo over land from EOS MODIS and MISR data: Theory and algorithm. J. Geophys. Res. 102, 171143–171161.

Weiss, M., Baret, F., Block, T., Koetz, B., Burini, A., Scholze, B., Lecharpentier, P., Brockmann, C., Fernandes, R., Plummer, S., Myneni, R., Gobron, N., Nightingale, J., Schaepman-Strub, G., Camacho, F., Sanchez-Azofeifa, A., 2014. On line validation exercise (OLIVE): A web based service for the validation of medium resolution land products. application to FAPAR products. Remote Sens. 6, 4190–4216. doi:10.3390/rs6054190

Weiss, M., Baret, F., Garrigues, S., Lacaze, R., 2007. LAI and fAPAR CYCLOPES global products derived from VEGETATION. Part 2: validation and comparison with MODIS collection 4 products. Remote Sens. Environ. 110, 317–331. doi:10.1016/j.rse.2007.03.001

ANNEX I. GOOGLE EARTH VIEWS AT 1KM^2 OVER GROUND REFERENCE HOMOGENEOUS SITES

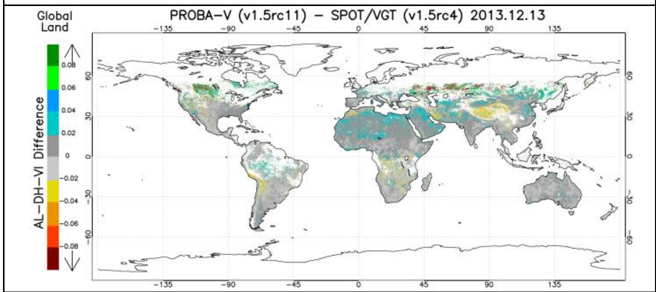
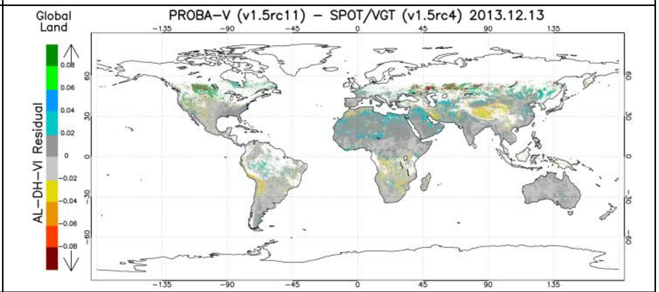
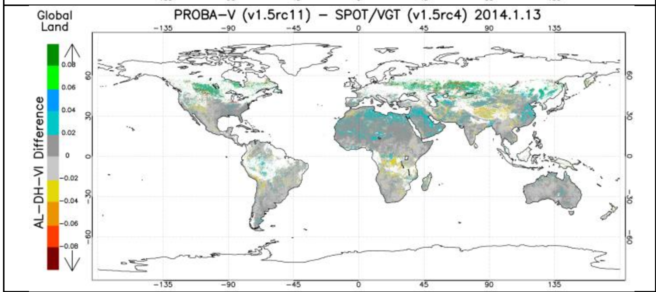
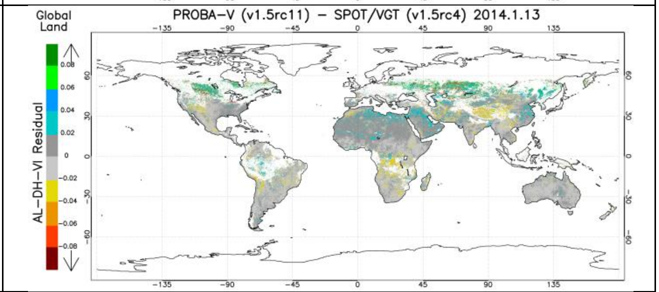
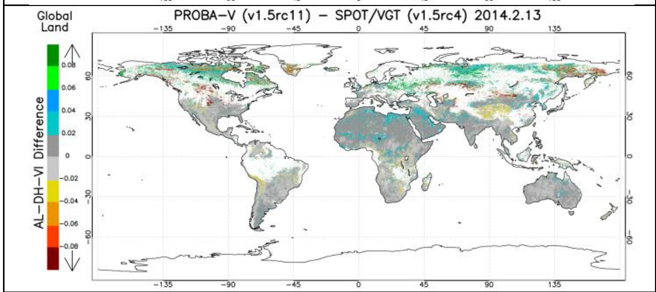
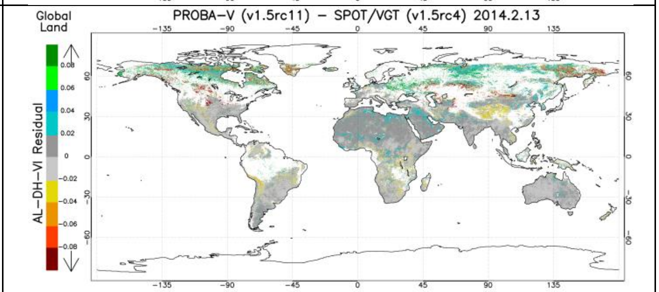
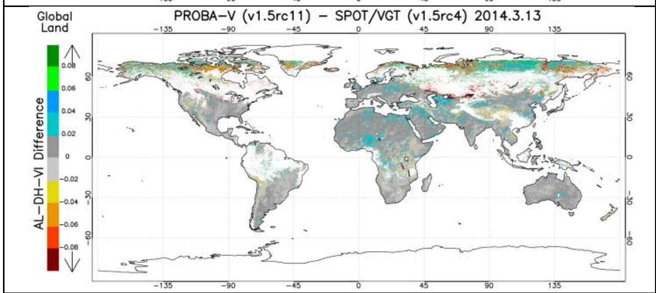
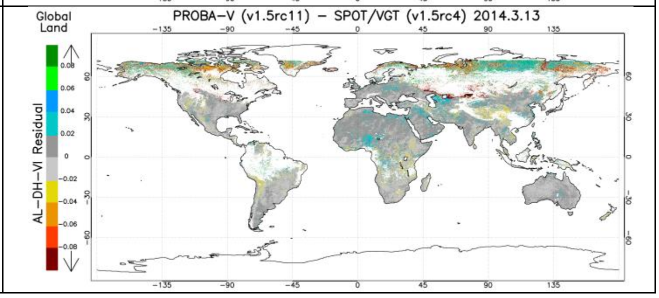
Bondville (USA). SURFRAD (40.05, -88.37)	Table Mountain Boulder (USA). SURFRAD (40.13, -105.24)	Desert Rock (USA). SURFRAD (36.63, -116.02)
		
Fort Peck (USA). SURFRAD (48.32, -105.1)	Sioux Falls (USA). SURFRAD (43.73, -96.62)	BilyKriz (Czech Rep). EFDC (49.50, 18.54)
		

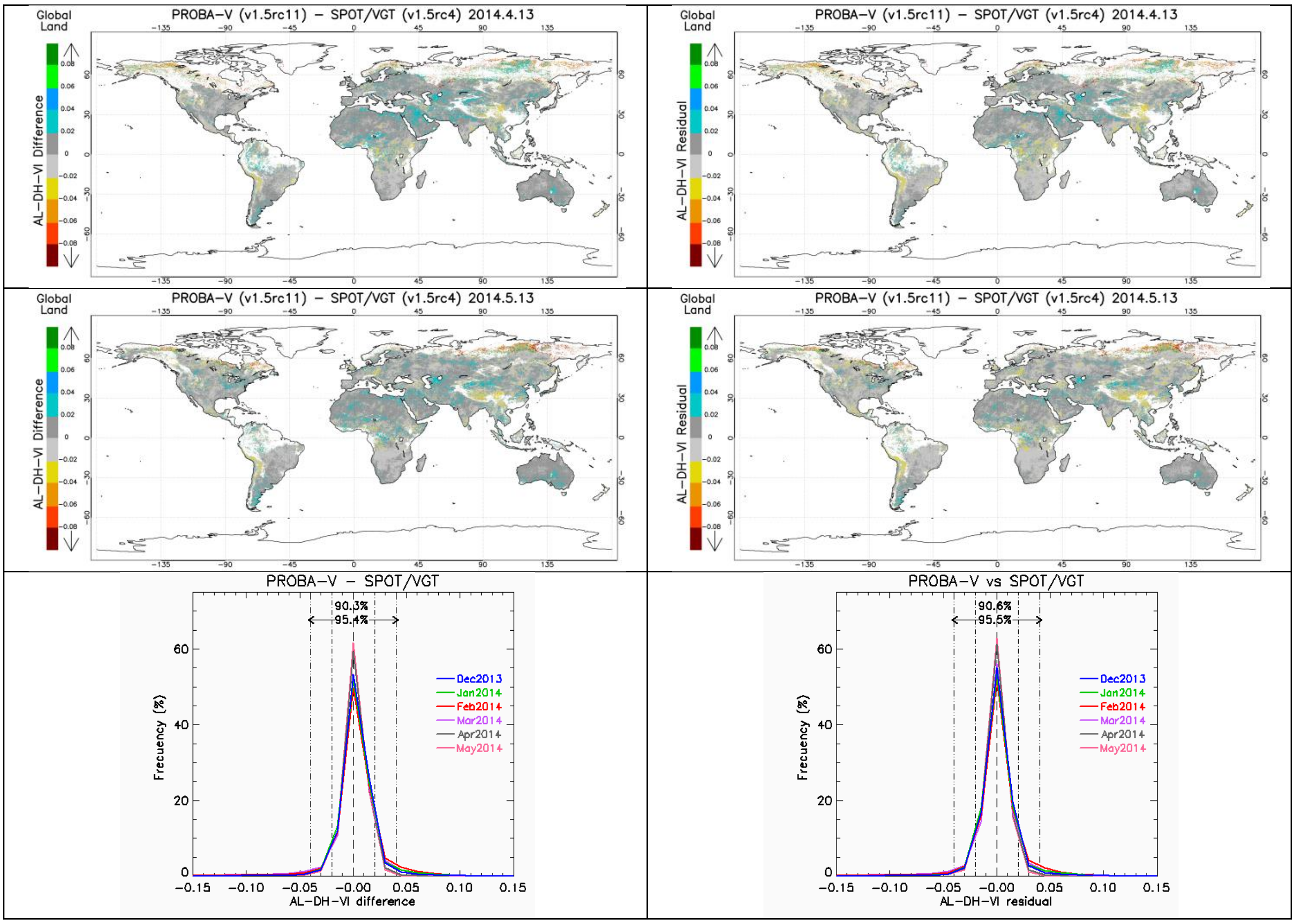
Oberbärenburg (Germany). EFDC (50.78, 13.72)	Cortes de Pallas (Spain). EFDC (39.22, -0.90)	Majadas del Tietar (Spain). EFDC (39.94, -5.77)
		
Puechabon (France). EFDC (43.74, 3.60)	Guyaflux (French Guaiana). EFDC (5.28, -52.92)	Collelongo (Italy). EFDC (41.85, 13.59)
		
Brody (Poland). EFDC (52.43, 16.30)	Zackenberg Heath(Denmark). EFDC (74.47, -20.55)	Monte Bondone (Italy). EFDC (46.02, 11.05)
		

Tharandt (Germany). EFDC (50.96, 13.57)	Tuczno (Poland). EFDC (53.19, 16.10)
	

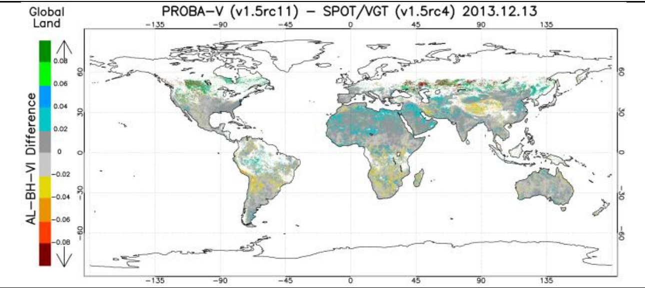
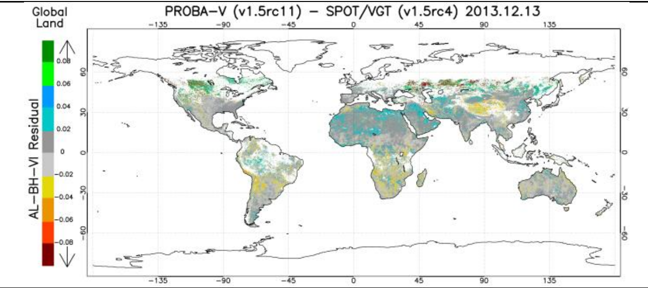
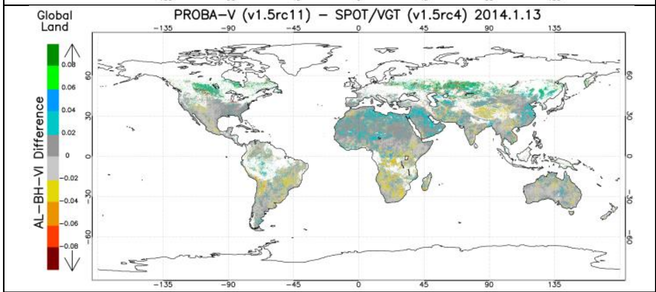
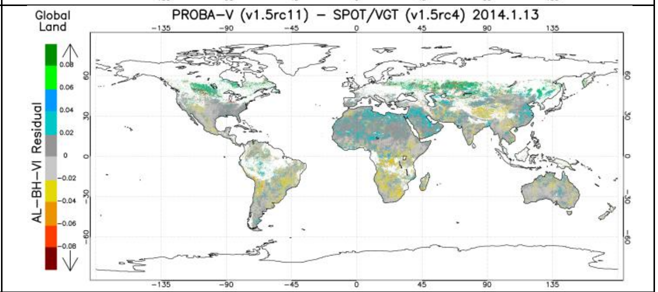
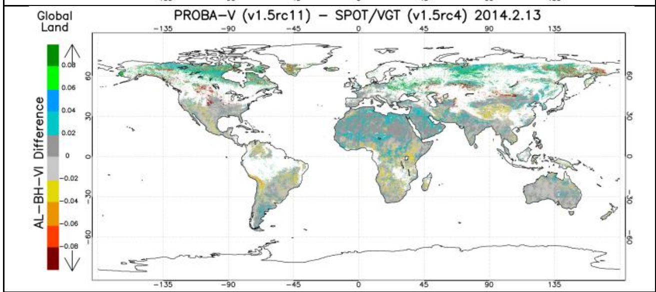
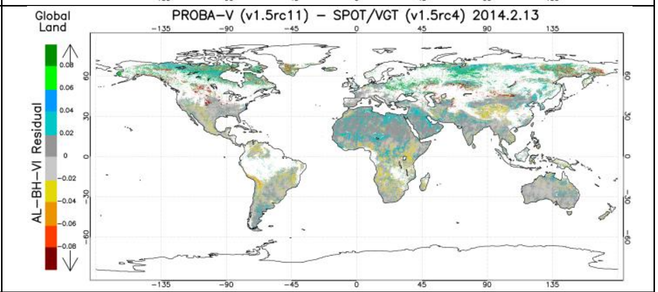
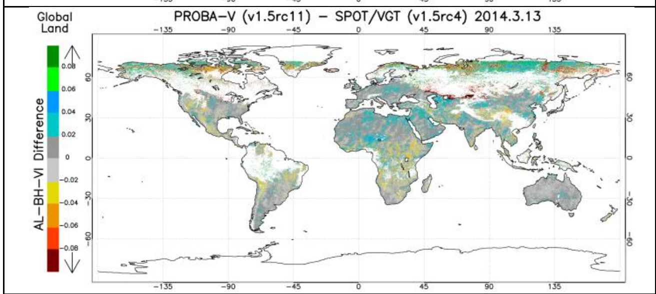
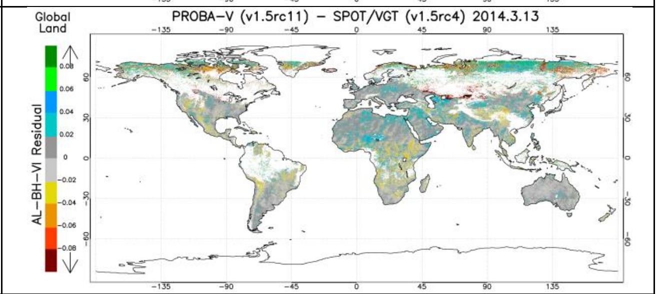
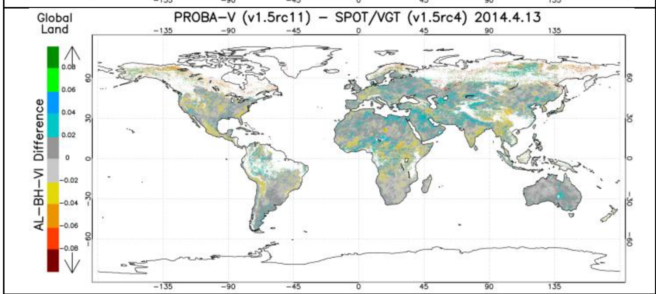
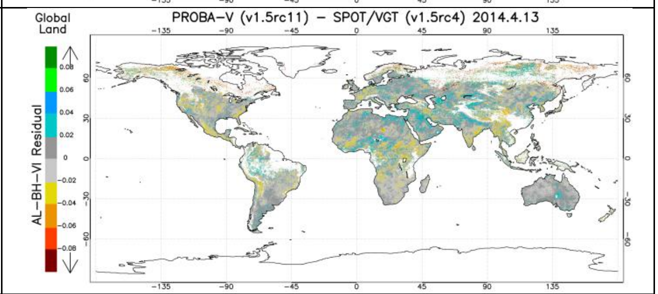
ANNEX II. DIFFERENCE MAPS AND MAPS OF RESIDUALS BETWEEN PROBA-V AND SPOT/VGT SA V1.5

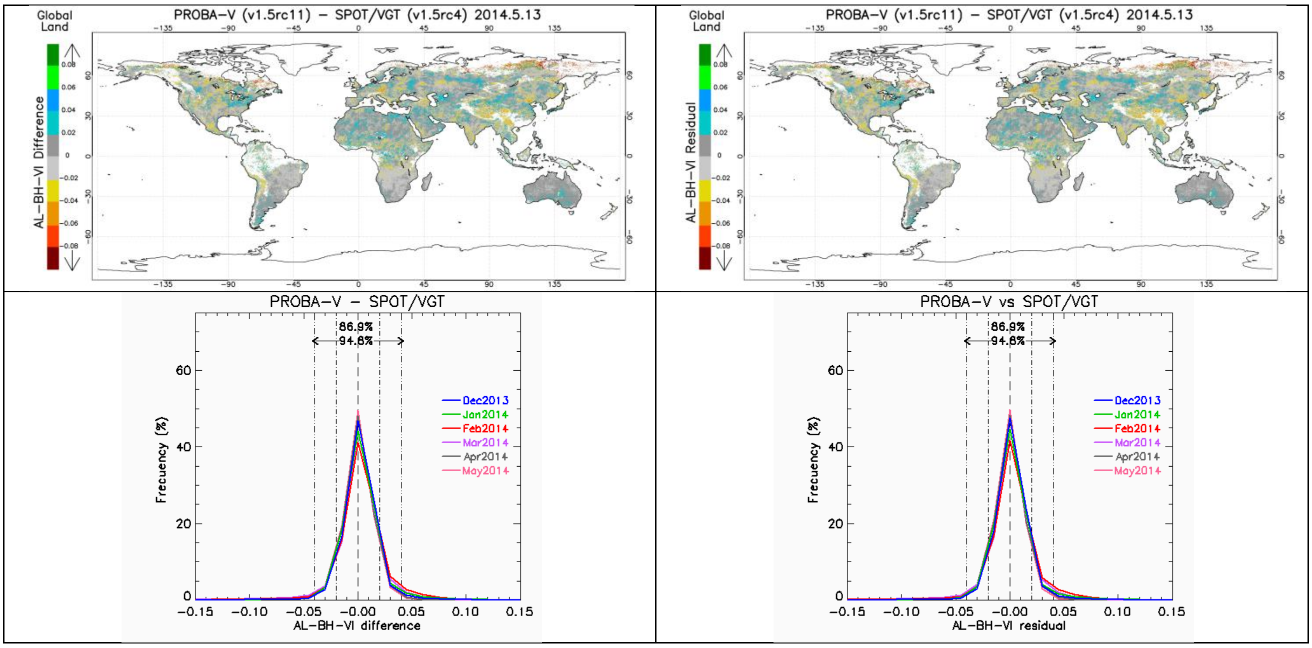
➢ AL-DH-VI

DIFFERENCES	RESIDUALS
	
	
	
	

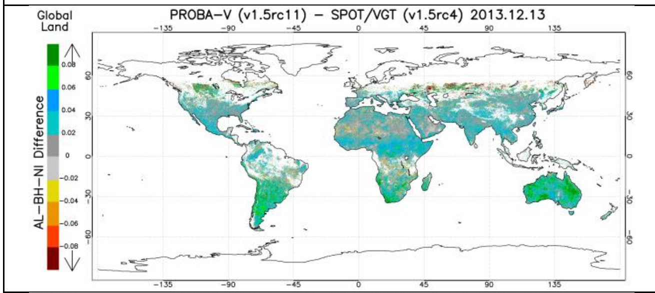
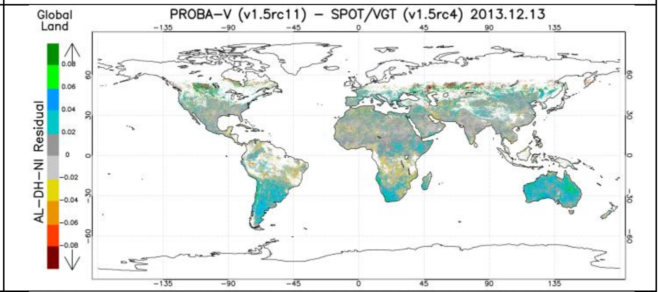
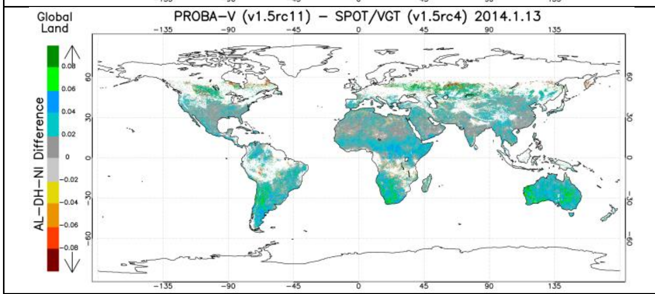
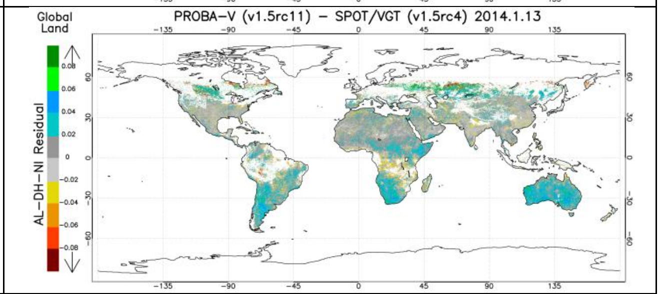
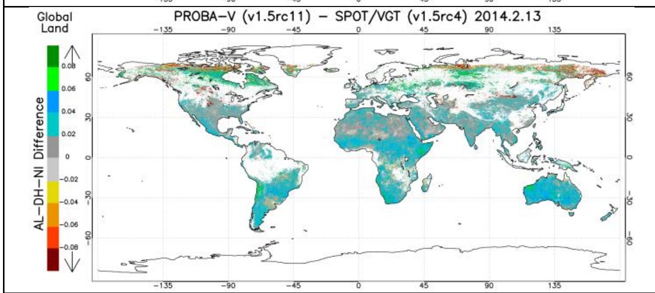
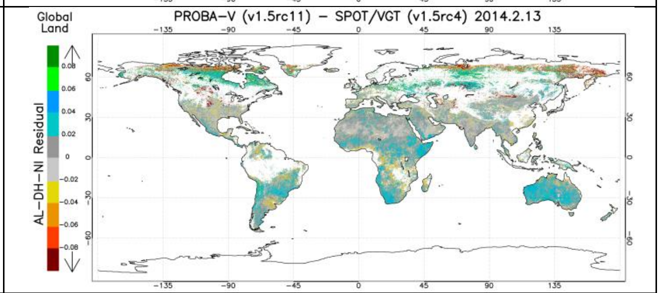
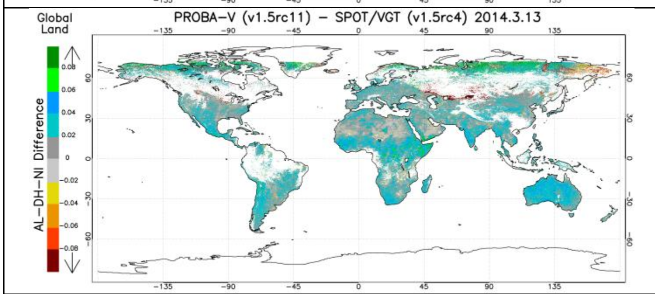
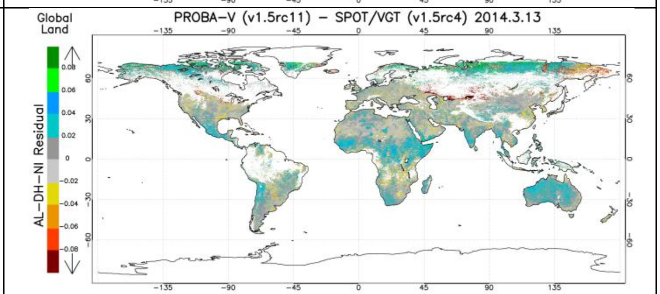
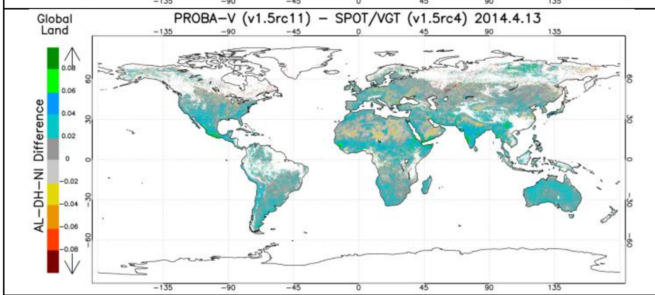
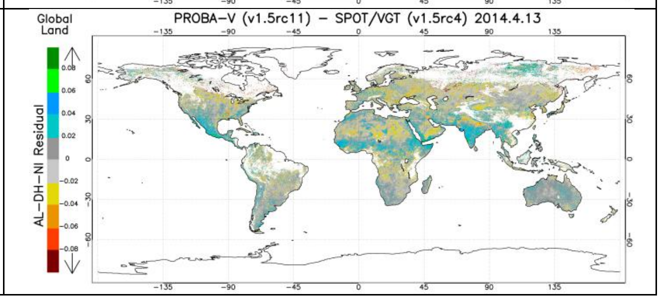

Global Land
PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.4.13
AL-DH-VI Difference
Global Land
PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.4.13
AL-DH-VI Residual
Global Land
PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL-DH-VI Difference
Global Land
PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL-DH-VI Residual
PROBA-V – SPOT/VGT
90.3%
95.4%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL-DH-VI difference
PROBA-V vs SPOT/VGT
90.6%
95.5%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL-DH-VI residual

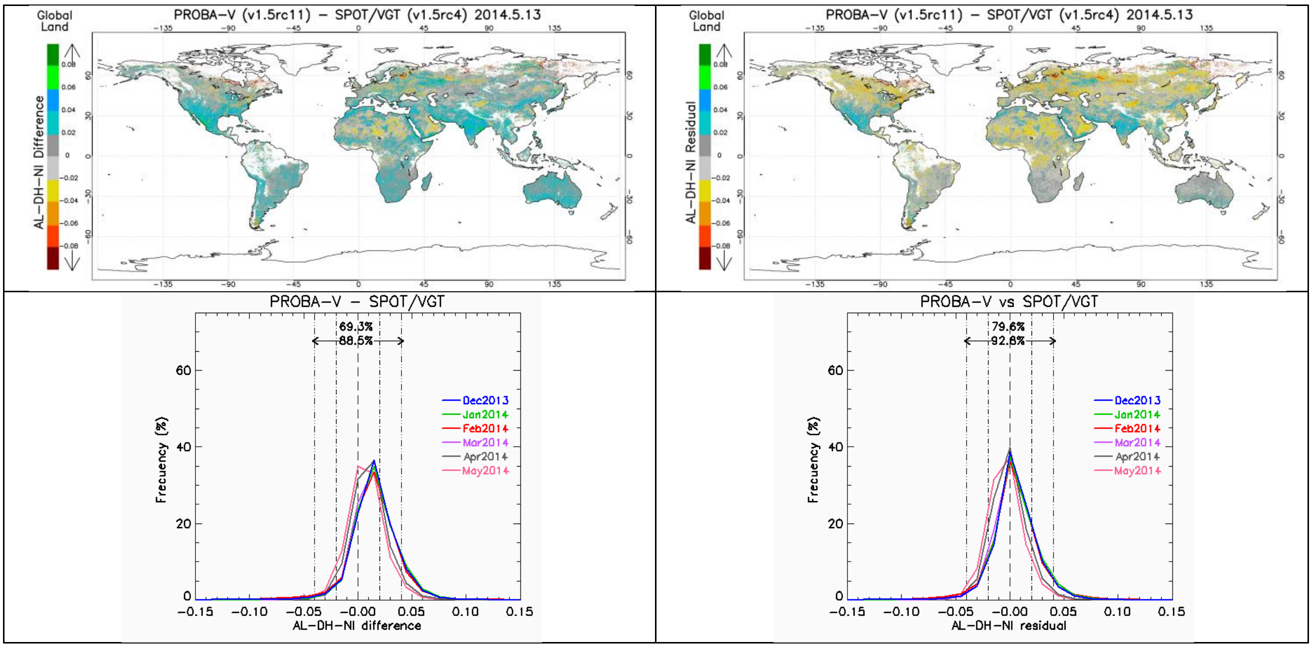
➢ AL-BH-VI

DIFFERENCES	RESIDUALS
	
	
	
	
	

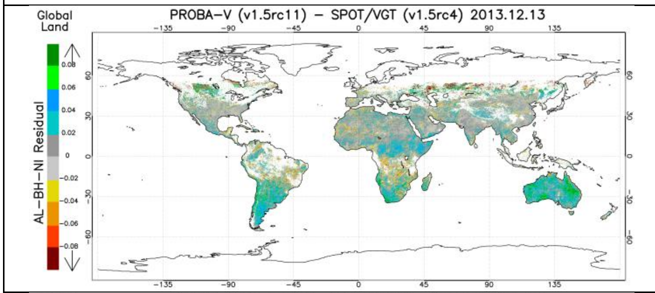
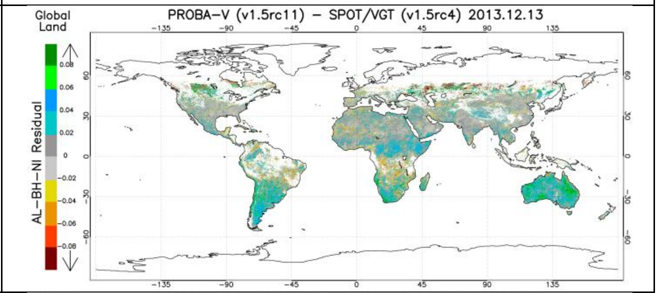
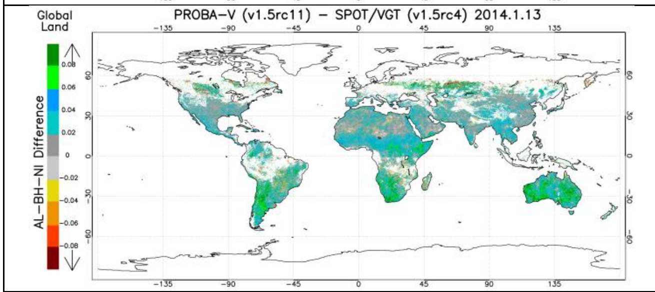
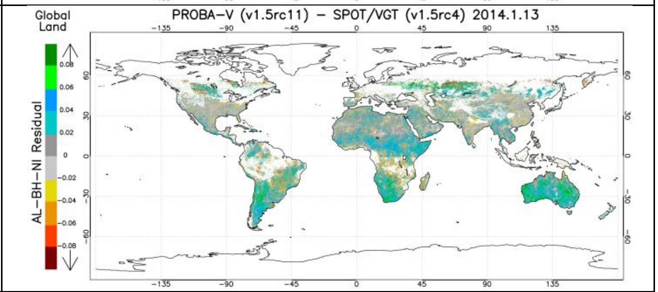
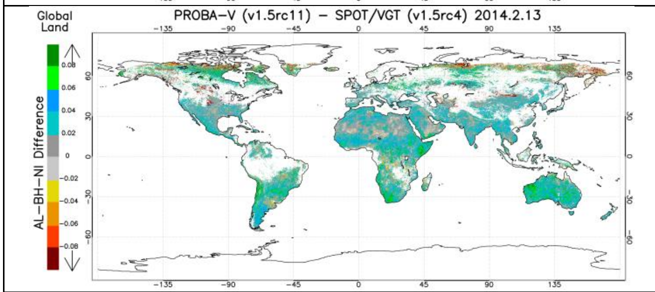
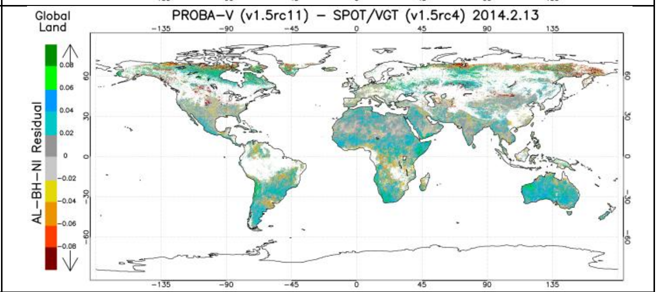
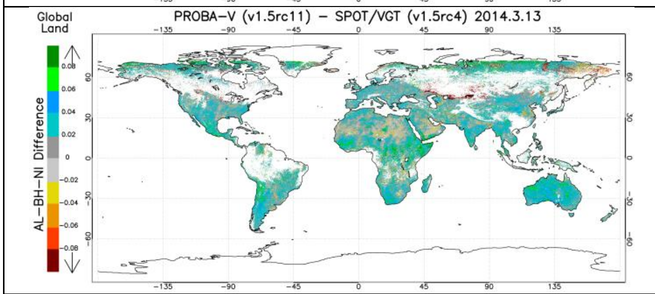
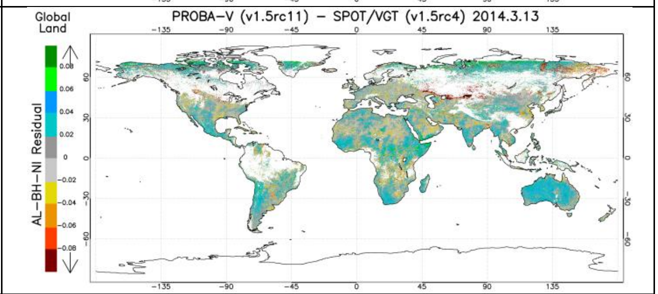
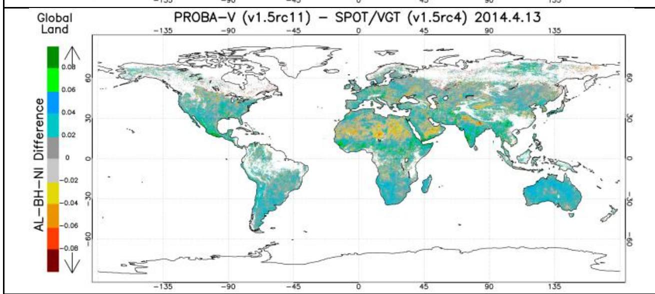
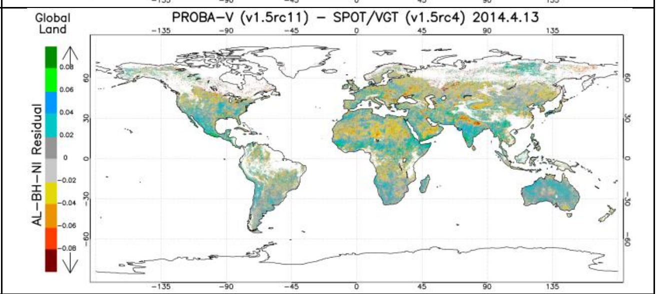

Global Land
PROBA–V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL–BH–VI Difference
Global Land
PROBA–V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL–BH–VI Residual
PROBA–V – SPOT/VGT
86.9%
94.8%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL–BH–VI difference
PROBA–V vs SPOT/VGT
86.9%
94.8%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL–BH–VI residual

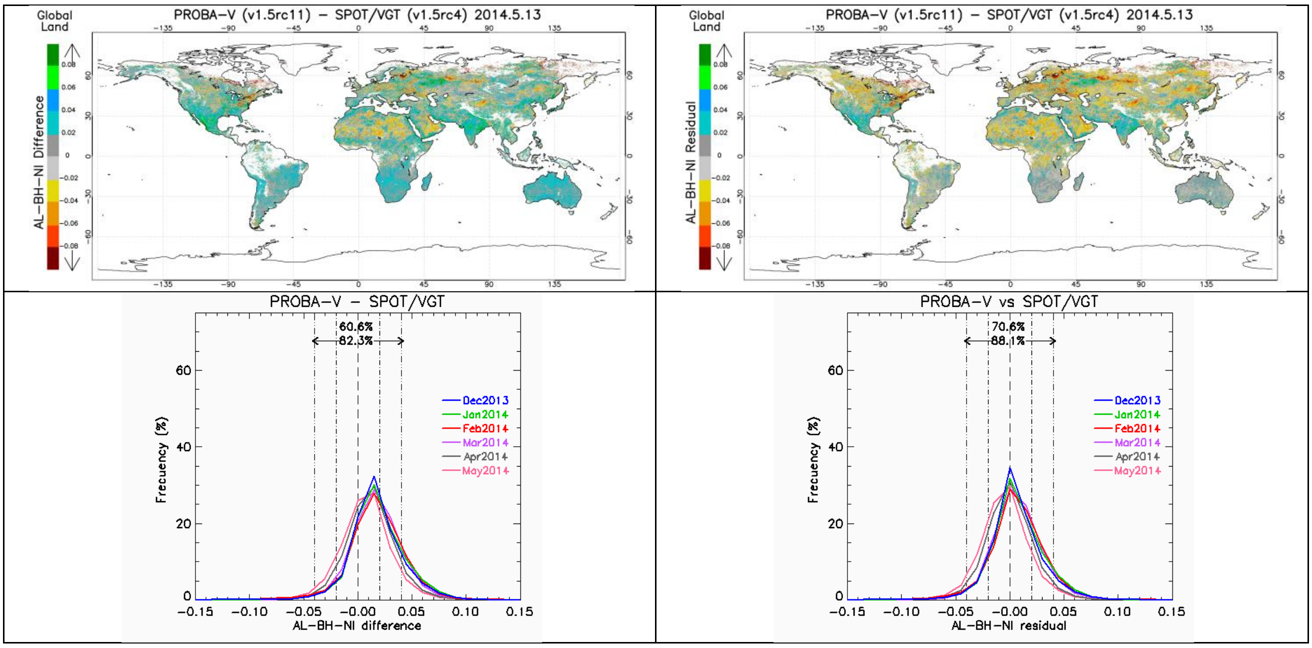
➢ AL-DH-NI

DIFFERENCES	RESIDUALS
	
	
	
	
	

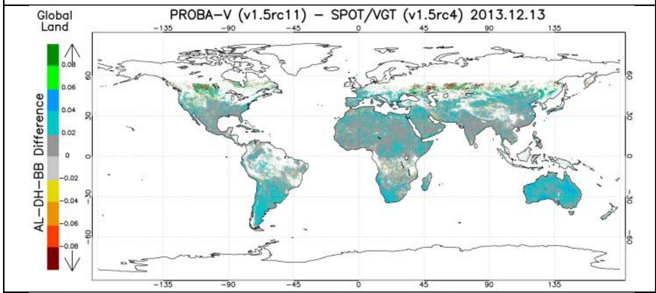
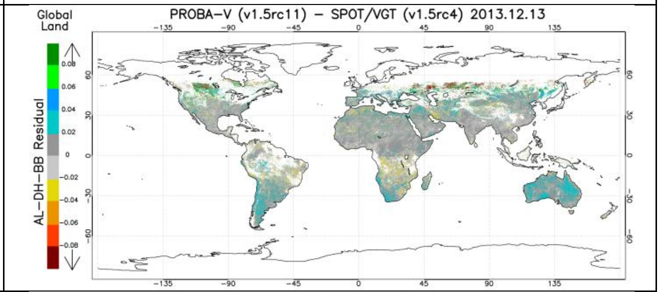
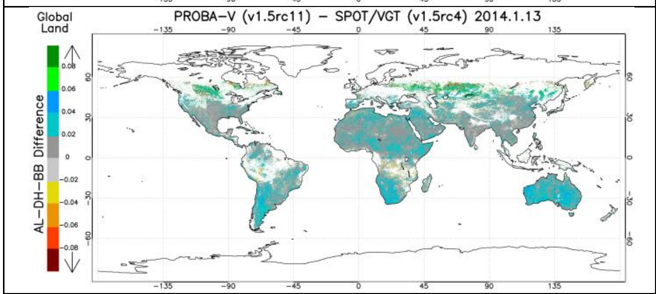
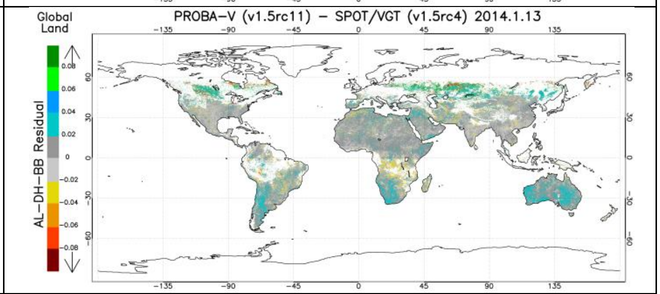
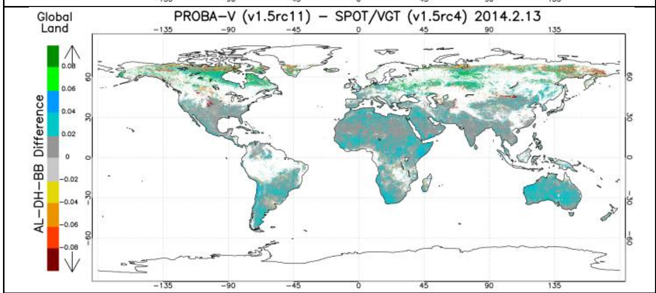
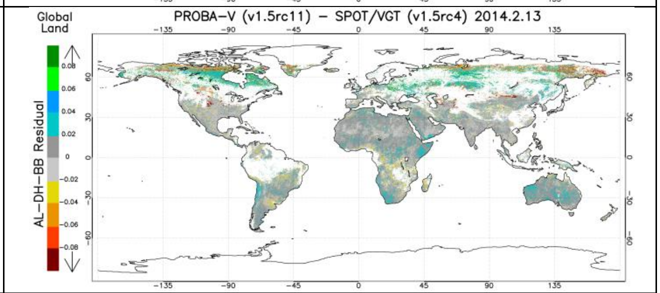
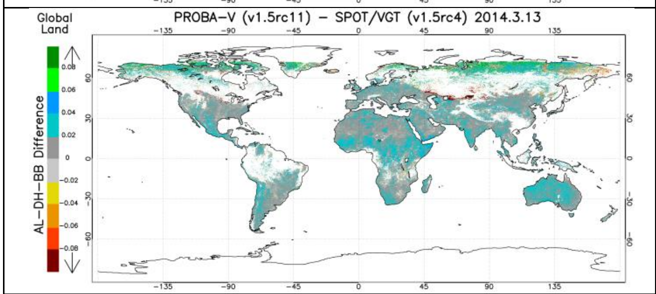
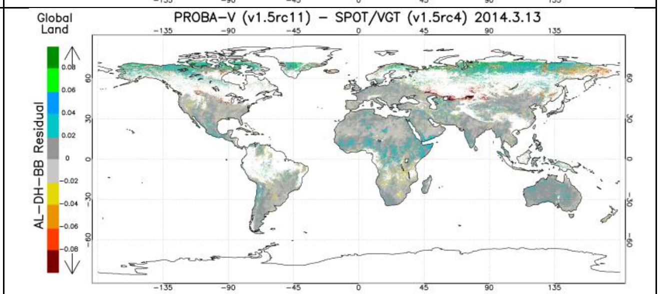
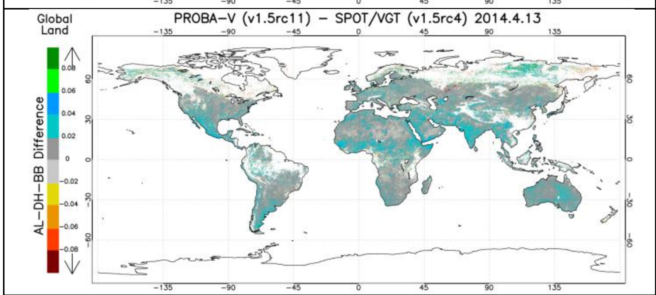
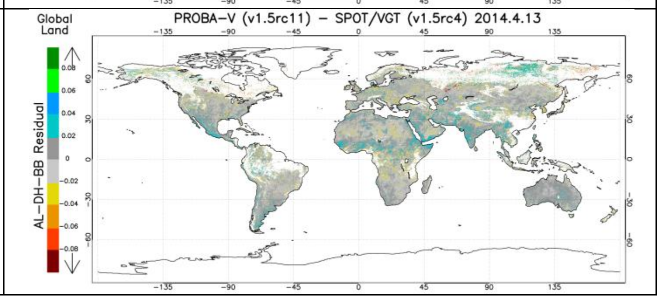

PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
Global Land
AL-DH-NI Difference
AL-DH-NI Residual
PROBA-V – SPOT/VGT
PROBA-V vs SPOT/VGT
69.3%
88.5%
79.6%
92.8%
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
Frecuency (%)
AL-DH-NI difference
AL-DH-NI residual

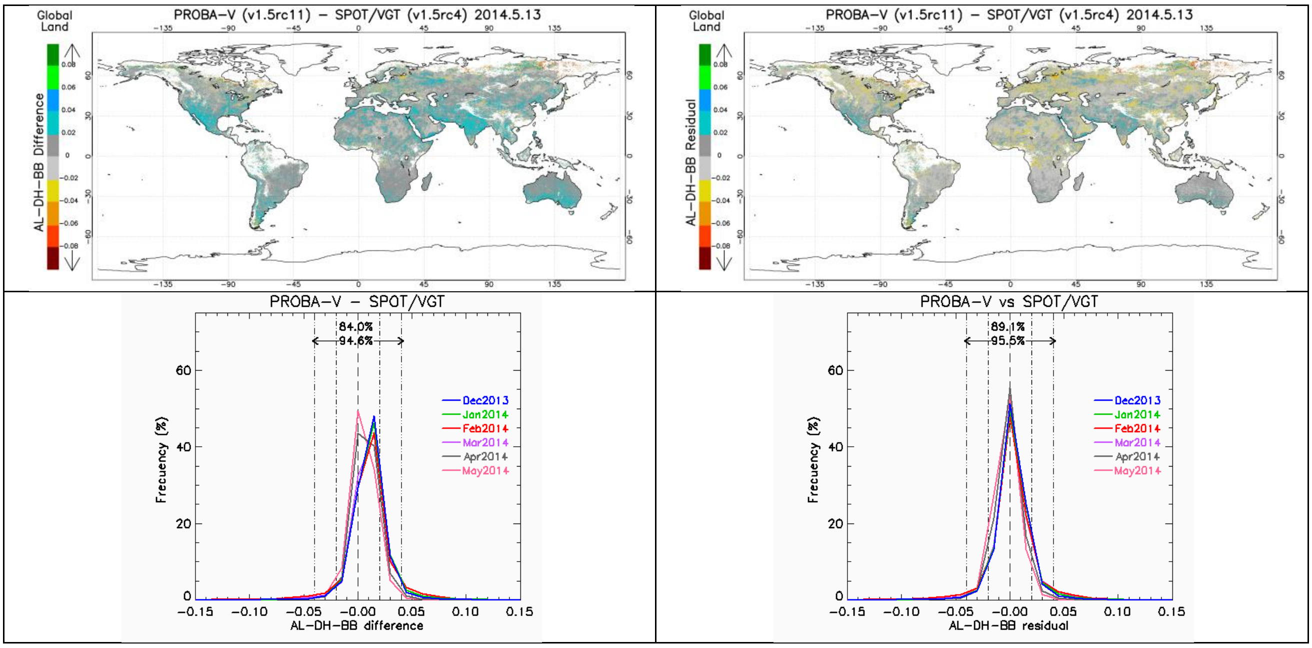
➢ AL-BH-NI

DIFFERENCES	RESIDUALS
	
	
	
	
	

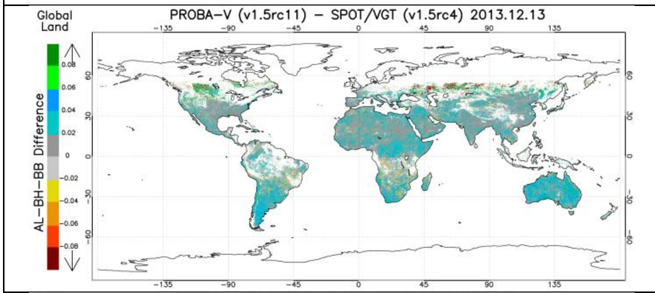
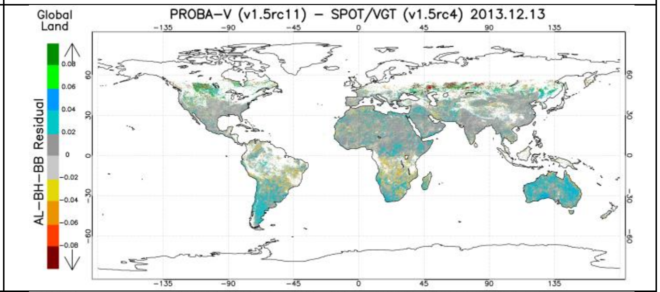
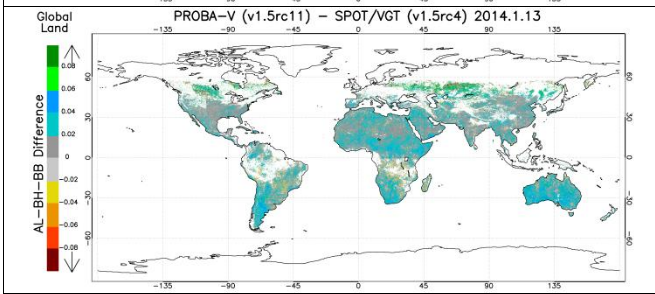
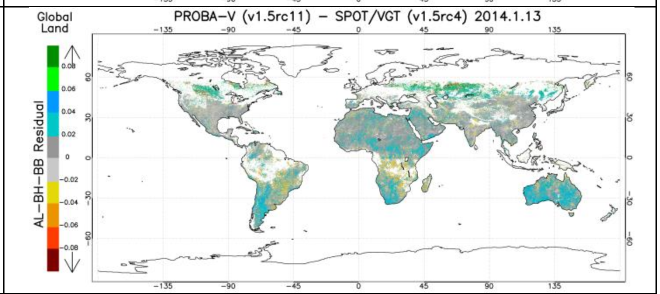
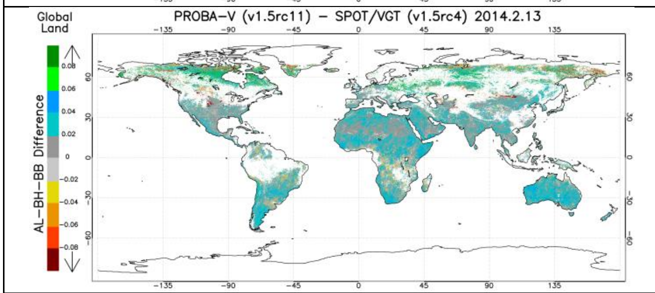
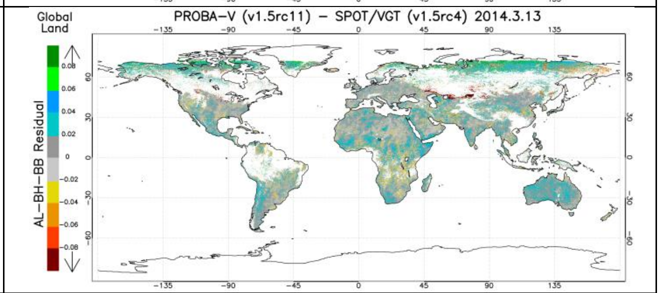
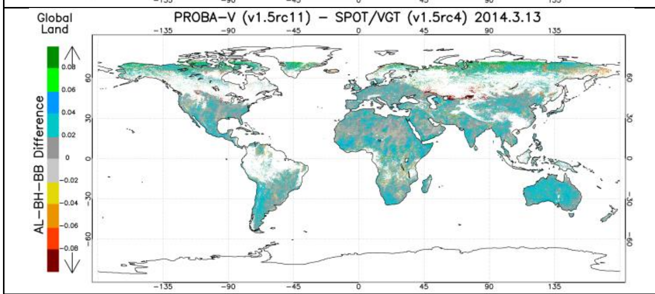
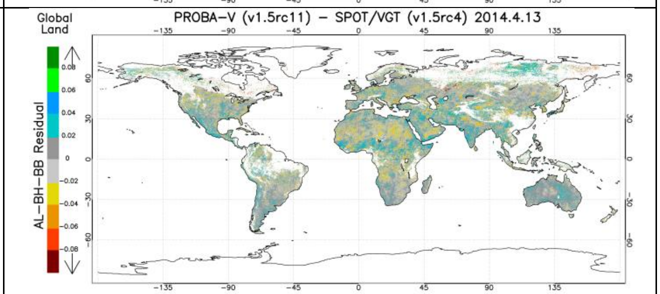
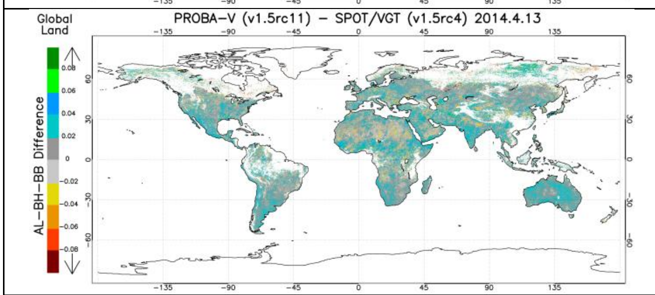
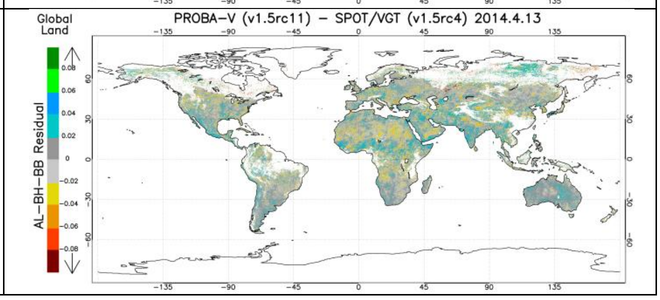

Global Land
PROBA–V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL–BH–NI Difference
Global Land
PROBA–V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL–BH–NI Residual
PROBA–V – SPOT/VGT
60.6%
82.3%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL–BH–NI difference
PROBA–V vs SPOT/VGT
70.6%
88.1%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL–BH–NI residual

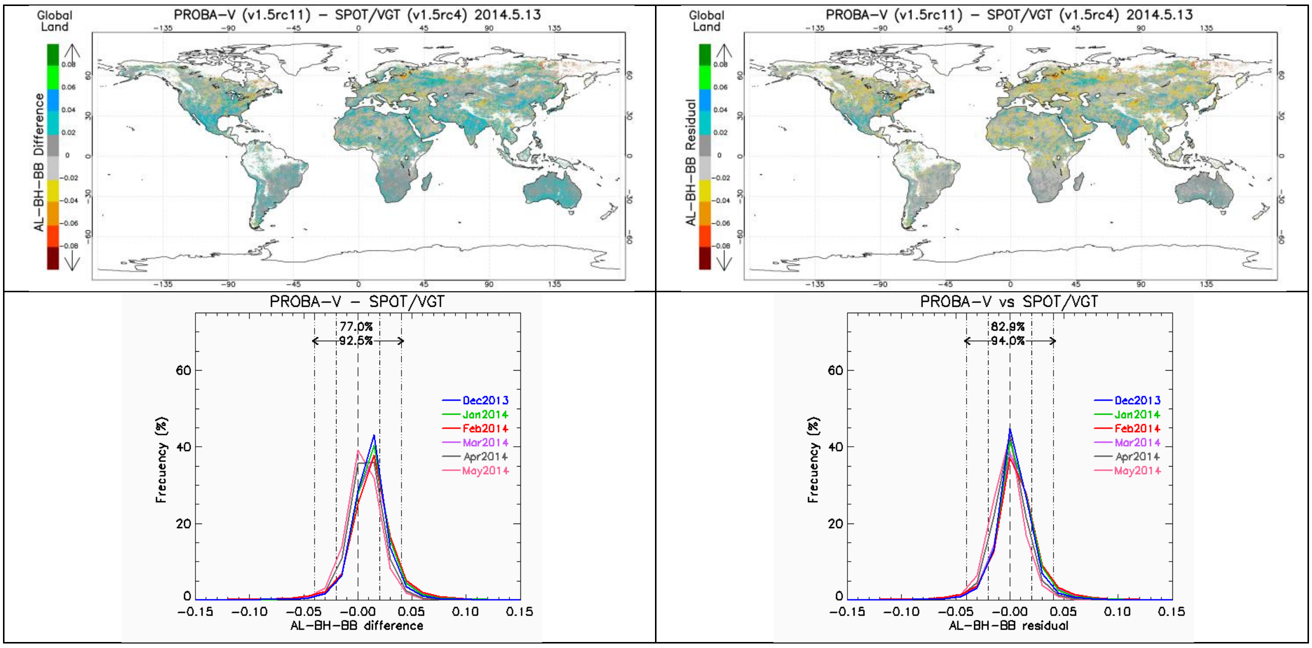
➢ AL-DH-BB

DIFFERENCES	RESIDUALS
	
	
	
	
	


Global Land
PROBA–V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
AL–DH–BB Difference
AL–DH–BB Residual
PROBA–V – SPOT/VGT
PROBA–V vs SPOT/VGT
84.0%
94.6%
89.1%
95.5%
Frecuency (%)
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
AL–DH–BB difference
AL–DH–BB residual

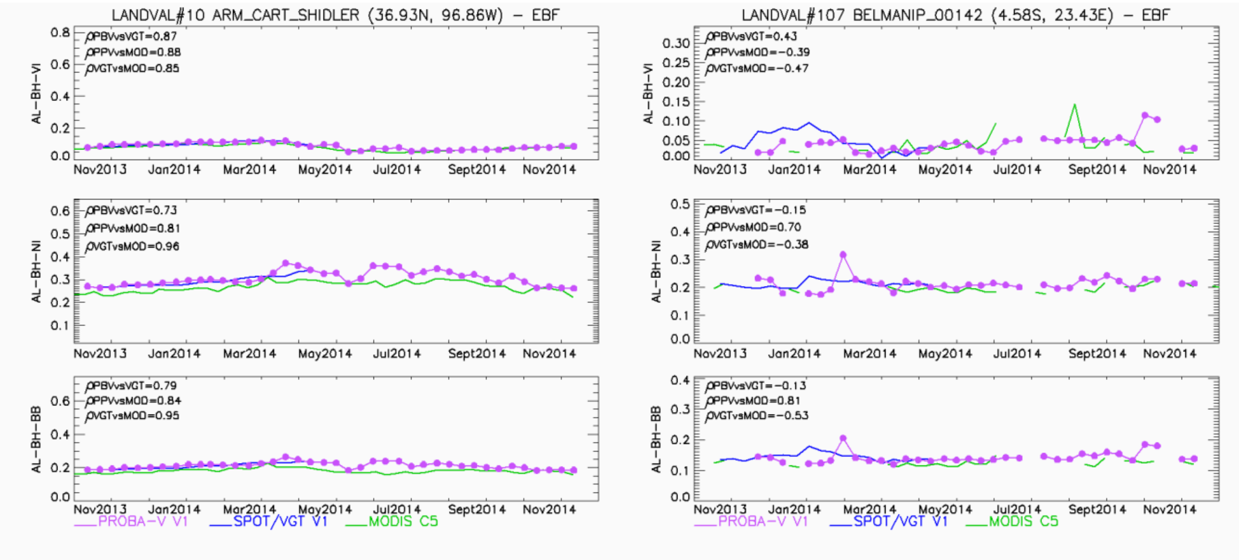
➢ AL-BH-BB

DIFFERENCES	RESIDUALS
	
	
	
	
	

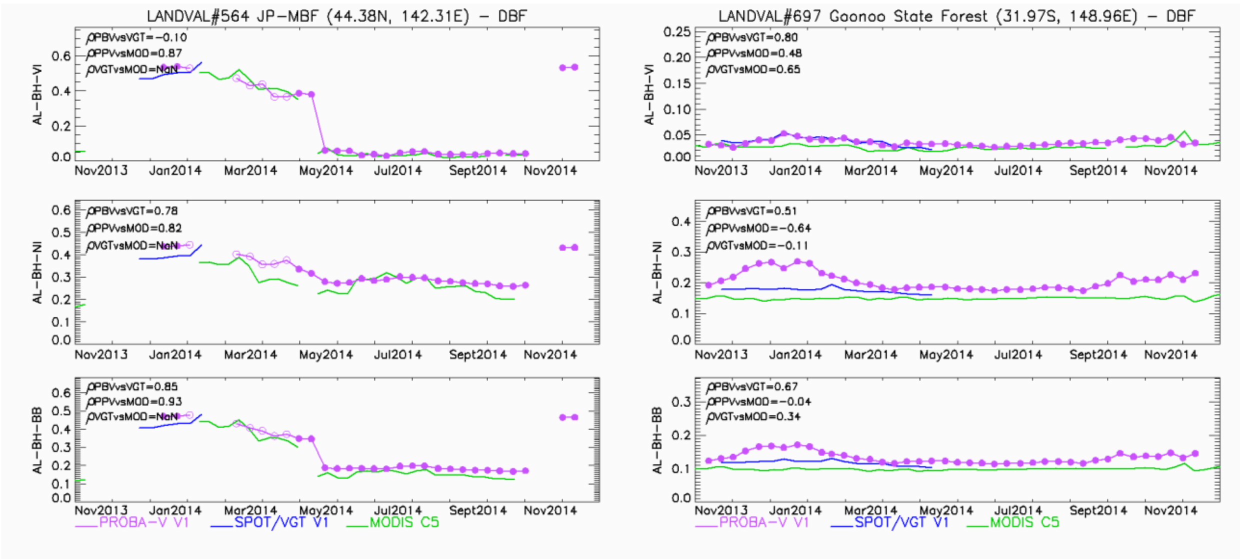

PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
Global Land
AL-BH-BB Difference
PROBA-V (v1.5rc11) – SPOT/VGT (v1.5rc4) 2014.5.13
Global Land
AL-BH-BB Residual
PROBA-V – SPOT/VGT
77.0%
92.5%
Frecuency (%)
AL-BH-BB difference
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014
PROBA-V vs SPOT/VGT
82.9%
94.0%
Frecuency (%)
AL-BH-BB residual
Dec2013
Jan2014
Feb2014
Mar2014
Apr2014
May2014

ANNEX III. Selection of Additional Temporal Profiles of White-Sky Albedo

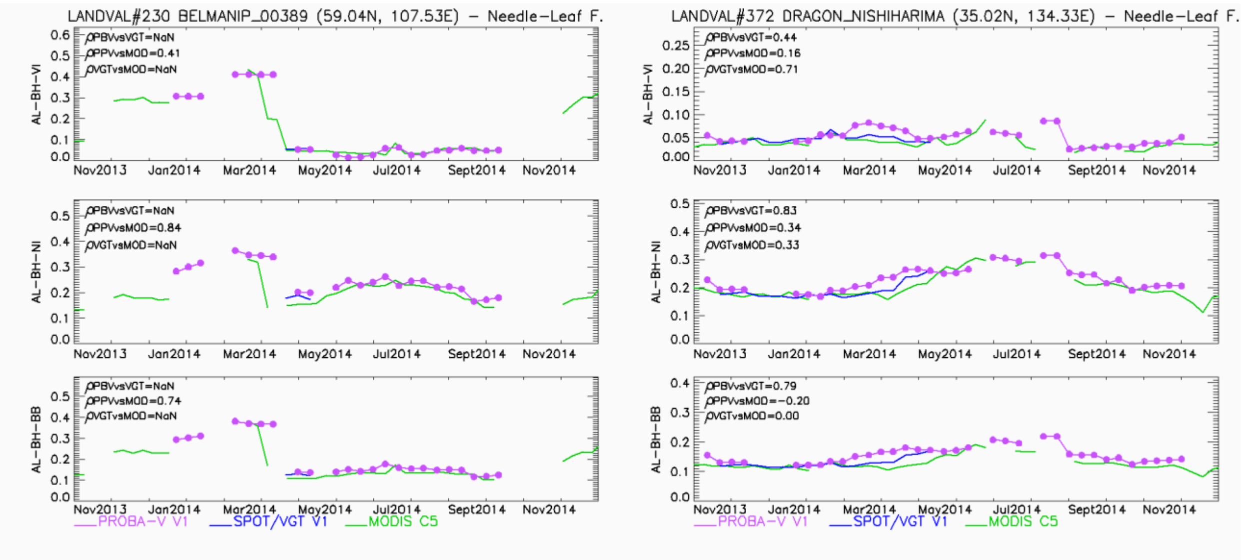
Evergreen Broadleaved Forest



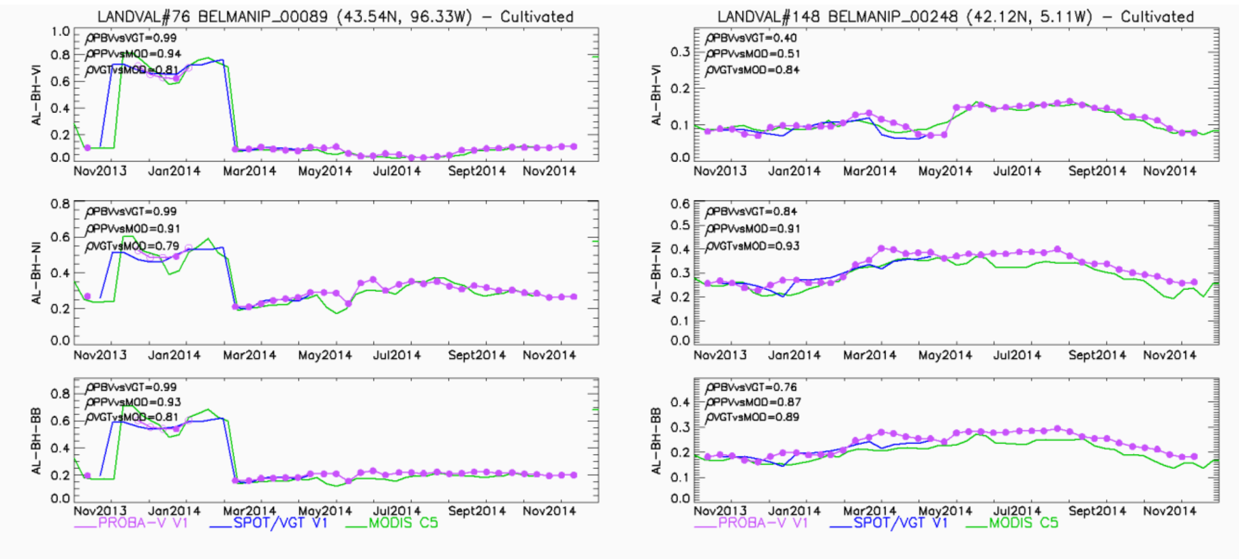
Deciduous Broadleaved Forest



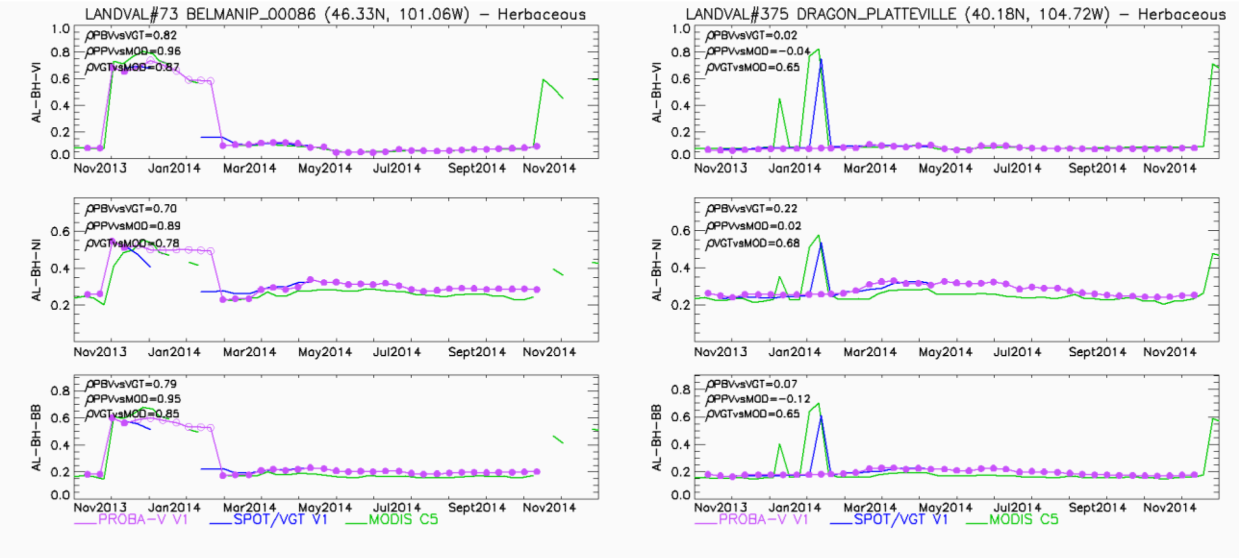
Needle-Leaf Forest



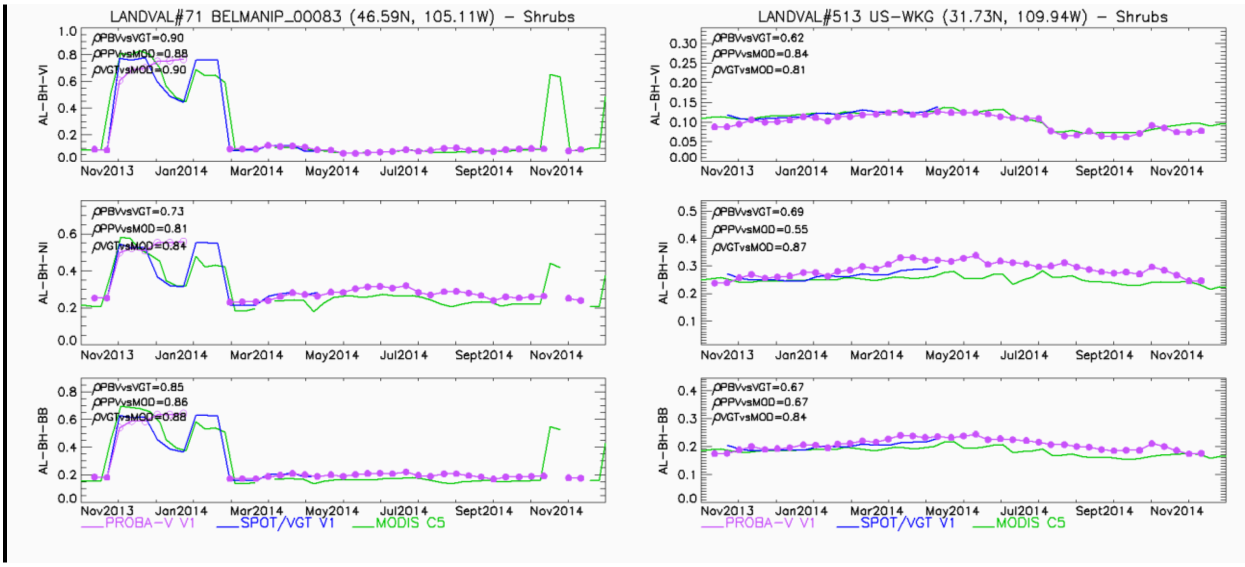
Cultivated



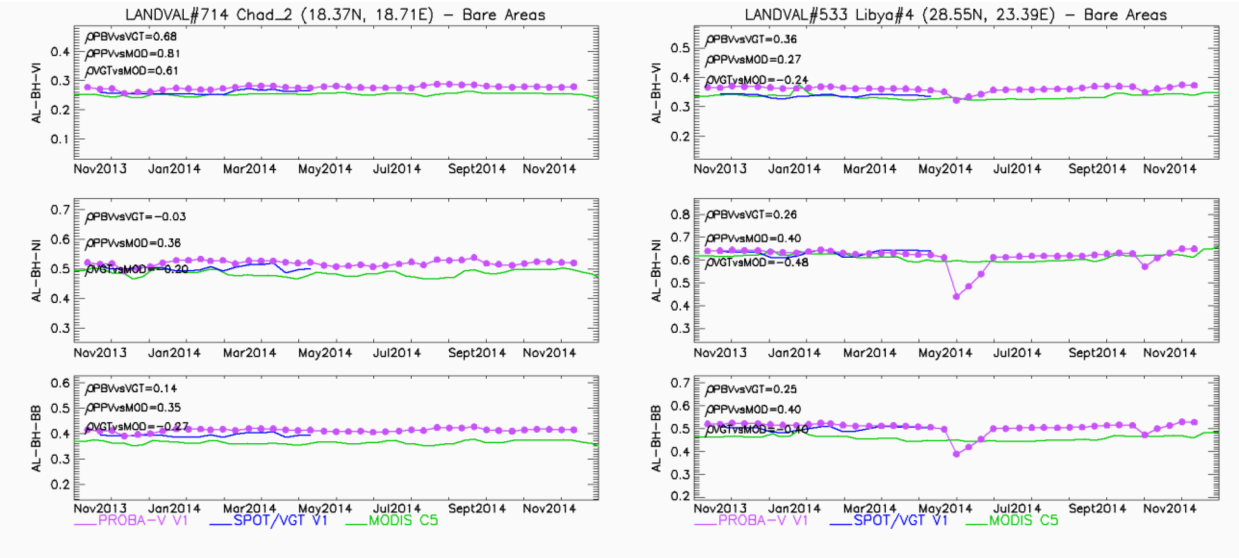
Herbaceous



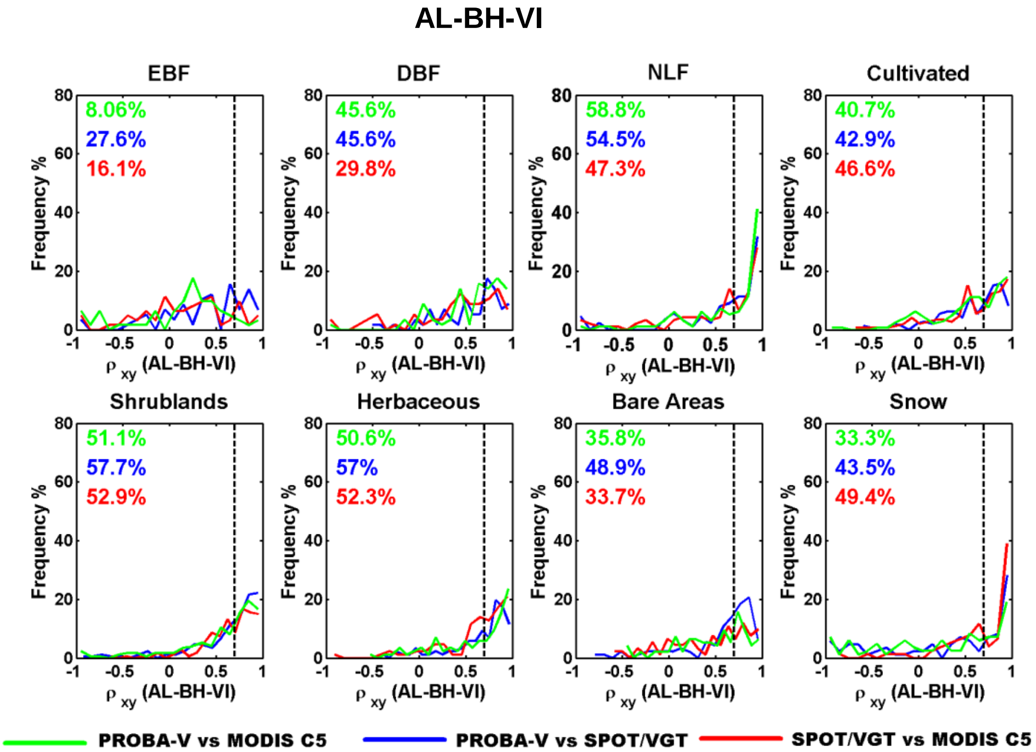
Shrublands



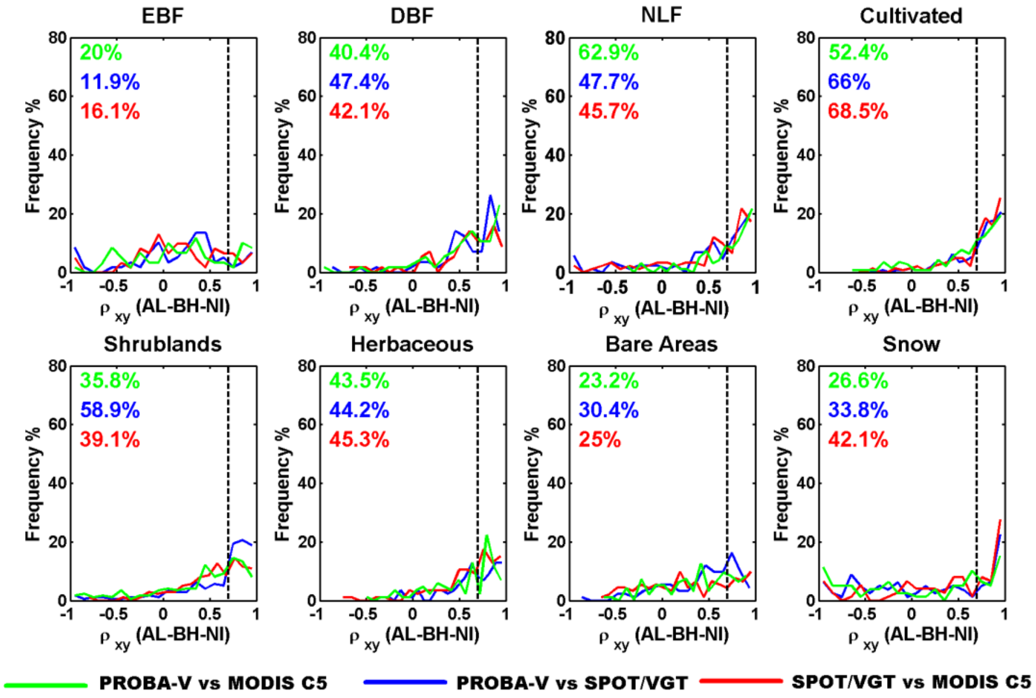
Bare Areas


LANDVAL#714 Chad_2 (18.37N, 18.71E) – Bare Areas
LANDVAL#533 Libya#4 (28.55N, 23.39E) – Bare Areas
AL-BH-VI
AL-BH-NI
AL-BH-BB
PROBA-V V1
SPOT/VGT V1
MODIS C5

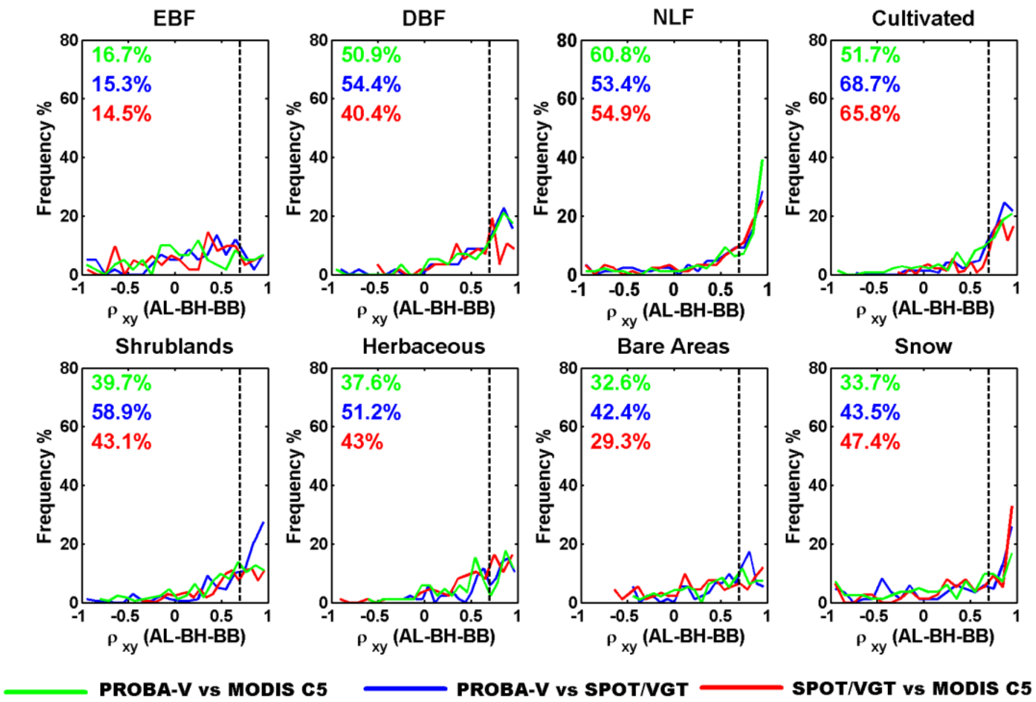
ANNEX IV. CROSS-CORRELATION DISTRIBUTIONS FOR WHITE-SKY ALBEDOS



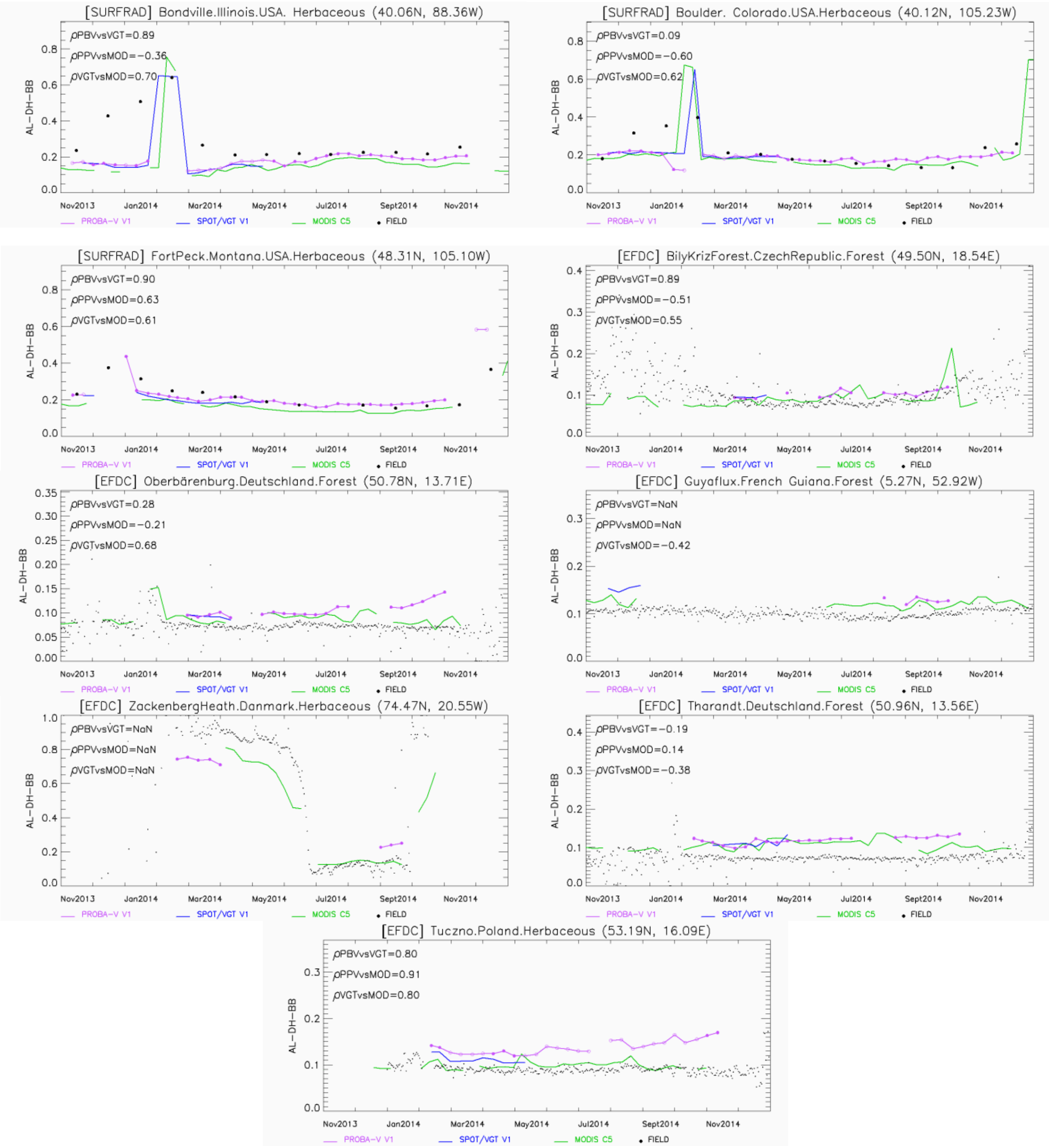
AL-BH-NI



AL-BH-BB



ANNEX V. Additional Temporal Profiles over SURFRAD and EFDC stations.



DIGITAL ANNEX

Complete set of graphs

Digital Annex can be downloaded in the "Documents" tab from the following link:

http://land.copernicus.eu/global/products/sa

The Digital Annex contains the following folders and information:

- **GLOBAL MAPS:** Plots of the global maps (at 1/16 reduced resolution) of PROBA-V SA V1.5 products (AL-DH-VI, AL-DH-NI, AL-DH-B, AL-BH-VI, AL-BH-NI and AL-BH-BB) and ancillary layers (ERR, NMOD, QFLAG).
- **TEMPORAL PROFILES:** Temporal profiles of PROBA-V V1.5, SPOT/VGT V1.5 and MODIS C5 SA products over the 725 LANDVAL sites, organized per biome type.
- **SPATIO-TEMPORAL CONSISTENCY:** Results for two periods:
  - **Dec13-May14:** Overall scatter-plots between PROBA-V and SPOT/VGT SA V1.5 products (and scatter-plots per biome types and continental region) and box-plots per bin. Histograms of retrievals and differences of PROBA-V SA V1.5, SPOT/VGT SA V1.5 and MODIS C5.
  - **Jan14-Dec14:** Overall scatter-plots between PROBA-V SA V1.5 and MODIS C5 SA products (and scatter-plots per biome types and continental region) and box-plots per bin. Histograms of retrievals and differences of PROBA-V SA V1.5 and MODIS C5.