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”Operation of the Global Land Component”

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QUALITY ASSESSMENT REPORT

SURFACE ALBEDO – VERSION 1
SPOT/VEGETATION

Issue I1.10

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List of Acronyms

AL-DH-VI	Broadband Directional Hemispheric Reflectance over visible band.
AL-DH-NI	Broadband Directional Hemispheric Reflectance over NIR band.
AL-DH-BB	Broadband Directional Hemispheric Reflectance over total spectrum.
AL-BH-VI	Broadband Bi-Hemispheric Reflectance over visible band.
AL-BH-NI	Broadband Bi-Hemispheric Reflectance over NIR band.
AL-BH-BB	Broadband Bi-Hemispheric Reflectances over total spectrum.
ATBD	Algorithm Theoretical Basis Document
BDF	Broadleaf Deciduous Forest
BEF	Broadleaf Evergreen Forest
BELMANIP	BEnchmark Land Multisite ANalysis and Intercomparison of Products
BRDF	Bidirectional Reflection Distribution Function
CCD	Charge-Coupled Device
CEOS	Committee on Earth Observation Satellite
CEOS LPV	**CEOS** Land Product Validation Subgroup
CNES	Centre National d'ÉtudesSpatiales
CYCLOPES	Carbon cYcle and Change in Land Observational Products from an Ensemble of Satellites
ECV	Essential Climate Variables
FAPAR	Fraction of PAR absorbed by the vegetation
FLUXNET	Flux Network
GCOS	Global Climate Observing System
GIO	GMES Initial Operations
GL	Copernicus Global Land service
GTOS	Global Terrestrial Observing System
GMES	Global Monitoring for Environment and Security
JRC	Joint Research Centre (European Commission)
LAI	Leaf Area Index
LSA SAF	Land Surface Analysis Satellite Application Facility
MCDC5	MODIS Terra+Aqua products Colletcion 5
MCSS	Minimum Consistent Spatial Support
MDAL	MSG Daily Albedo
MODIS	Moderate Resolution Imaging Spectroradiometer
MSG	Meteosat Second Generation
NASA	National Aeronautics and Space Administration (USA)
NIR	Near Infra-Red
NLF	Needle leaf Forest
NRT	Near Real Time
PAR	Photosynthetically Active Radiation
PDF	Probability Density Function
PUM	Product User Manual
QF	Quality Flag
RMSE	Root Mean Square Error

RTLSR	RossThick LiSparse-Reciprocal
SBA	Sparse and Bare Areas
SEVIRI	Spinning Enhanced Visible and InfraRed Imager (EUMETSAT)
SMAC	Simplified Model for Atmospheric Correction
SPOT /VGT	Satellite Pour l'Observation de la Terre / VEGETATION
SWIR	Shortwave Infra-Red
TOA	Top Of Armosphere
TOC	Top Of Canopy
VIS	Visible waveband
WGCV	Working Group on Calibration and Validation (CEOS)
WMO	World Meteorological Organization

1 BACKGROUND OF THE DOCUMENT

1.1 EXECUTIVE SUMMARY

From 1st January 2013, the Global Land (GL) component of the Copernicus Land service is providing a series of bio-geophysical products describing the status and evolution of land surface at global scale. Essential Climate Variables like the Leaf Area Index (LAI), the Fraction of PAR absorbed by the vegetation (FAPAR), the surface albedo, the Land Surface Temperature, the soil moisture, the burnt areas, the areas of water bodies, and additional vegetation indices, are generated every hour, every day or every 10 days from Earth Observation satellite data. Production and delivery of the parameters are performed on a reliable, automatic and timely manner and are complemented by the constitution of long term time series.

Quality Assessment and continuous Quality Monitoring constitute the only means of guaranteeing the compliance of generated products with user requirements:

- The former concerns the new products which must pass an exhaustive scientific evaluation before to be implemented operationally.
- The latter concerns the operational products to check if their quality keeps at the same level along the time.

For both, the procedures follow, as much as possible, the guidelines, protocols and metrics defined by the Land Product Validation (LPV) group of the Committee on Earth Observation Satellite (CEOS) for the validation of satellite-derived land products. They are described in the Service Validation Plan [GIOGL1_SVP].

The Global Land service provides a surface albedo product derived from SPOT/VEGETATION sensor data, part of the known GEOV1 product family. It contains a directional albedo (AL-DH), and a hemispherical albedo (AL-BH) calculated in the three spectral domains (visible [0.4, 0.7µm], near infrared [0.7, 4µm] and total shortwave spectrum [0.3-4µm]).

The quality assessment exercise, performed on 2 years (2006-2007) and reported in this document, shows that the GL SPOT/VGT GEOV1 Albedo product is of good quality over the globe, presenting some limitation under snow conditions. The product reach good performance for most of the criteria examined, even though the error field seems not realistic and the Quality Flag may discard reliable snow retrievals. Regarding these results, the GL SPOT/VGT GEOV1 SA product can be released to the user community. The successive quality monitoring analysis carried out every 6 months on the recent NRT products (2013-2014) demonstrate that the products keep the same level of quality.

1.2 SCOPE AND OBJECTIVES

The document presents the results of the quality assessment of the SPOT/VGT GEOV1 Surface Albedo product. The directional albedo (AL-DH) and hemispherical albedo (AL-BH) in the three spectral domains were analysed following the same procedure. Nevertheless, for sake of clarity, the discussion is mainly focussed on the total broadband directional albedo product (AL-DH-BB). The main objectives are:

- Quantify the performance of the SPOT/VGT Albedo products by comparing it with ground reference data over a significant set of locations and time periods.
- Assess the consistency of the SPOT/VGT Albedo products by comparing it with similar products over globally representative locations and time periods.
- Provide to the user relevant information about the scientific merit of the SPOT/VGT Albedo products.

1.3 CONTENT OF THE DOCUMENT

This document is structured as follows:

- Chapter 2 recalls the users requirements, and the expected performance
- Chapter 3 describes the content of the GL SPOT/VGT GEOV1 albedo product along with the retrieval algorithm.
- Chapter 4 introduces the reference albedo products used for the intercomparison
- Chapter 5 presents the methodology for quality assessment, the metrics, the criteria of evaluation, and the available ground data
- Chapter 6 shows the results of the analysis
- Chapter 7 gives the main conclusions
- Chapter 8 reports the outcome of the quality monitoring performed every 6 months on the near-real-time (NRT) products
- Chapter 9 makes recommendations based upon the results

1.4 RELATED DOCUMENTS

1.4.1 Applicable documents

AD1: Annex II – Tender Specifications to Contract Notice 2012/S 129-213277 of 7th July 2012

AD2: Appendix 1 – Product and Service Detailed Technical requirements to Annex II to Contract Notice 2012/S 129-213277 of 7th July 2012

1.4.2 Input

Document ID	Descriptor
GIOGL1_SSD	Service Specifications Document of the Copernicus Global Land Service.
GIOGL1_SVP	Service Validation Plan of the Global Land Service

GIOGL1_ATBD_TOC-r	Algorithm Theoretical Basis Document of the SPOT/VGT GEOV1 normalized TOC reflectance
GIOGL1_ATBD_SAV1	Algorithm Theoretical Basis Document of the SPOT/VGT GEOV1 Surface Albedo product

1.4.3 Output

Document ID	**Descriptor**
GIOGL1_PUM_SAV1	Product User Manual summarizing all information about the SPOT/VGT GEOV1 Surface Albedo product

2 REVIEW OF USERS REQUIREMENTS

According to the applicable document [AD2], the user's requirements relevant for Surface albedo products are:

- **Definition:**

Surface albedo: it quantifies the fraction of the irradiance reflected by the surface of the Earth. Different albedos can be retrieved:

  - The directional albedo or directional-hemispherical reflectance (also called black-sky albedo) is defined as the integration of the bi-directional reflectance over the viewing hemisphere. It assumes all energy is coming from a direct radiation from the sun.
  - The hemispherical albedo or bi-hemispherical reflectance (also called white-sky albedo) is defined as the integration of the directional albedo over the illumination directions. It assumes all radiation coming in equal amounts from the entire hemisphere.

Likewise, the albedo can be assessed over each spectral band of the sensor, or integrated over large range of wavelengths. 3 broad wavelength ranges are used:

1. the visible (PAR) band: [0,4µm-0,7µm]

2. the near-infrared band: [0,7 µm-4 µm]

3. the total short-wave: [0,3 µm-4 µm]

- **Geometric properties**:
  - pixel size of 1/112° using a coordinate position of pixel centre
  - geodetical datum of WGS84.
- **Geographical coverage:**
  - Global coverage (180°W – 180°E, 80°N – 80°S) in regular latitude/longitude grid "plate-carrée) (40320 col, 14673 lines)
- **Accuracy requirements:**

The surface albedo is one of the terrestrial "Essential Climate Variables"(ECV) introduced by the Global Climate Observing System (GCOS). A number of principles have been established for satellite-based climate monitoring systems (GCOS-143, 2010). Specific requirements for the surface albedo as ECV are shown in Table 1 (GCOS-154, 2011).

In terms of Accuracy, for albedo values greater than 0.05, the accuracy required is 5% (see Figure 1, top). In terms of Stability, for albedo values greater than 0.01, the precision is 1% (see Figure 1, bottom). Therefore, the requirements in relative terms of 5% for accuracy and 1% of precision are mainly considered. Note that for the stability the requirement in absolute terms of 0.0001 is greater than the 1% for albedo values lower than 0.01. Therefore, this absolute requirement is a useless quantity.

Table 1: GCOS Requirements for surface albedo as Essential Climate Variables [GCOS-154, 2011].

Variable/ Parameter	Horizontal Resolution	Vertical Resolution	Temporal Resolution	Accuracy	Stability
Black and White-sky albedo	1 km	N/A	Daily to weekly	Max(5%; 0.0025)	Max(1%; 0.0001)

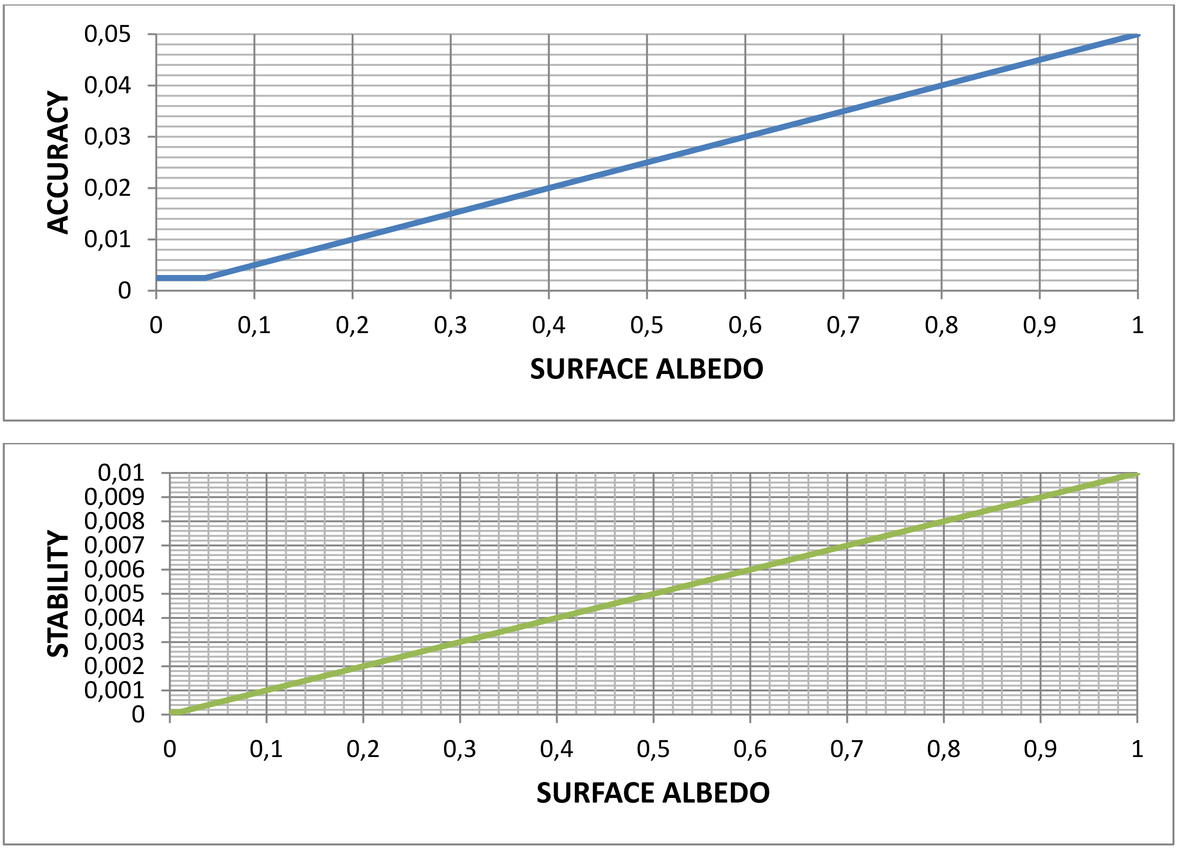


Figure 1: GCOS requirements as a function of albedo values. Top: Accuracy. Bottom: Stability.

- **Additional user requirements**

Additional 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" (http://www.wmo-sat.info/db/requirements/view/662). 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 2):

- Threshold: Minimum requirement;
- Breakthrough: Significant improvement;
- Goal: Optimum, no further improvement required (partly equivalent to GCOS requirements).

Table 2: WMO Requirements for surface albedo [source: http://www.wmo-sat.info/db/requirements/view/662].

	Goal	Breakthrough	Threshold
Uncertainty	5 %	7 %	10 %
Stability/decade (if applicable)	N/A	N/A	N/A
Horizontal Resolution	1 km	2 km	10 km
Vertical Resolution	N/A	N/A	N/A
Observing Cycle	24 hours	3 days	30 days
Timeliness	30 days	45 days	90 days

The WMO Observing Requirements Database specifies uncertainties in absolute parameter units. The stated “goal” uncertainty requirement of 5% is thus equivalent to the GCOS, but with a minimum requirement (threshold) of 10%.

Table 3: geoland2 User Requirements for surface albedo.

	Optimal	Target	Threshold
Accuracy	5 %	AL > 0.15: 10% AL < 0.15: 0.03	20 %

The users requirements expressed during geoland2/BioPar are shown in Table 3. Three accuracy levels were defined: Optimal, Target and Threshold. Optimal accuracy is defined as in GCOS and WMO, the target is here 10% and a threshold level of 20%.

The above requirements are indicative. They have to be adapted to the GL products and clarified by the User Board of the Global Land service.

3 THE GLOBAL LAND SPOT/VGT ALBEDO PRODUCT (GEOV1 ALBEDO)

Land surface albedo quantifies the fraction of energy reflected by the Earth's land surface, which is a key variable of the energy budget. The GL SPOT/VGT Albedo version 1 product (here termed as ALBEDO GEOV1), includes two albedo variables [GIOGL1_ATBD_SAV1]:

1) The directional albedo (AL-DH) or directional-hemispherical reflectance (so-called black-sky albedo) is defined as the integration of the bi-directional reflectance over the viewing hemisphere. It assumes all energy is co*ming* from a direct radiation from the sun. It is computed for the local solar noon.

2) The hemispherical albedo (AL-BH) or bi-hemispherical reflectance (so-called white-sky albedo) is defined as the integration of the directional albedo over the illumination hemisphere. It assumes a complete diffuse illumination.

These two albedo quantities are intrinsic properties of the surface and are governed by the optical and structural characteristics of the land cover type. They can be combined with information of the irradiance diffuse fraction to estimate an actual (so-called blue-sky) albedo.

The directional and hemispherical albedos are spectrally-integrated over three spectral domains: in the visible [0.4, 0.7μm], near infrared (NIR) [0.7, 4μm] and total short-wave spectrum [0.3-4μm]. As a result, the following albedo products are generated:

- AL-DH-VI: Broadband Directional Hemispheric Reflectance over visible band.
- AL-DH-NI: Broadband Directional Hemispheric Reflectance over NIR band.
- AL-DH-BB: Broadband Directional Hemispheric Reflectance over total spectrum.
- AL-BH-VI: Broadband Bi-Hemispheric Reflectance over visible band.
- AL-BH-NI: Broadband Bi-Hemispheric Reflectance over NIR band.
- AL-BH-BB: Broadband Bi-Hemispheric Reflectances over total spectrum.

Each albedo quantity has its corresponding error field, a Quality Flag of the product, an additional layer with the number of valid observations (NMOD) and, finally, a Land-Sea mask (LMK) field based on the GLC2000 land cover. Figure 2 shows an example of global map of the GEOV1 AL-DH-BB product for best quality input data and its corresponding error estimate.

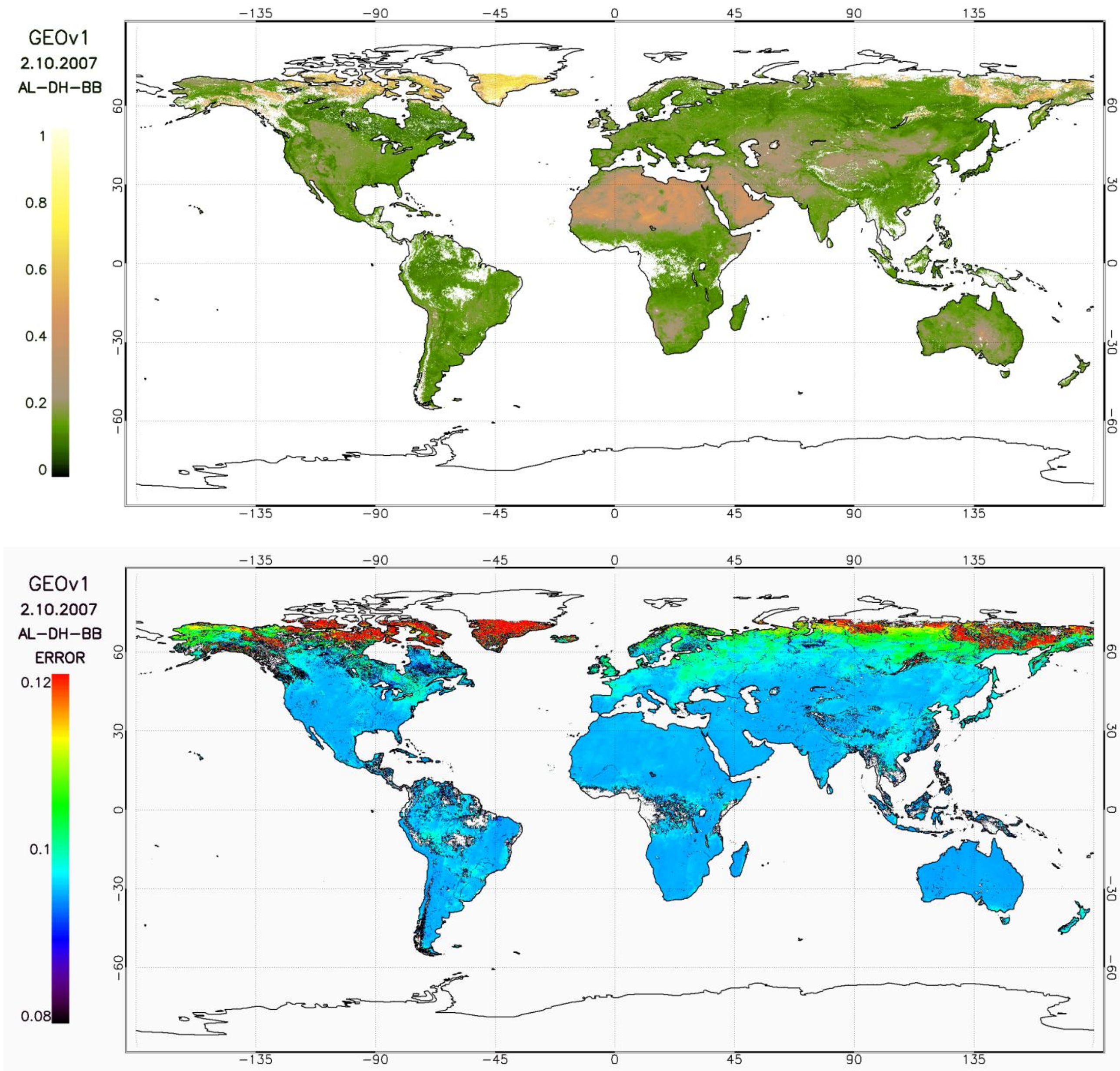


Figure 2. SPOT/VGT (GEOV1) shortwave directional albedo (AL-DH-BB) (top) and its error field (bottom) for the 2nd of October, 2007.

The algorithm has been defined by Météo-France/CNRM in the framework of the FP5/CYCLOPES project (Geiger and Samain, 2004). It is described in the ATBD of SPOT/VGT Albedo Product [GIOGL1_ATBD_SAV1] and summarized in the Product User Manual [GIOGL1_PUM_SAV1]. The algorithm follows the well-established approach for operational albedo determination based on semi-empirical BRDF kernel-driven models, which allows characterizing the angular dependence of the reflectance factor. First, the VEGETATION top-of-atmosphere (TOA) data is processed in order to get cloud-free top-of-canopy (TOC) reflectances (see comments on VGT input data below). Then, the spectral TOC reflectances acquired under different solar-viewing configurations during the synthesis period are used to invert 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. Note that for the compositing method prior information is used (Hagolle et al., 2004). 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 products are delivered in HDF5 format by tiles (10x10º) at the 10 days frequency. The projection is plate carrée, and the grid resolution is 1/112°.

The algorithm defined for the V1 is the same than the original CYCLOPES Algorithm (SPOT/VGT Albedo V0). Only the coefficients used to calculate the broadband albedos have been adapted to the re-calibrated SPOT/VEGETATION-2 data. In the V0, only the broadband directional albedos (AL-DH) are generated. Thus, the validation results obtained here for SPOT/VGT Albedo V1 are also valid for the SPOT/VGT Albedo V0.

Concerning the SPOT/VEGETATION input data, an anomaly has been identified in the processing chain. This anomaly concerns to the incorrect implementation of the standardization of solar illumination, which has a direct impact on the values of the TOA reflectance provided in VGT-P products. The impact in reflectance values can reach up to 6% depending on the period of the year. The maximum difference is reached in July as the date for the standardization is fixed to 1st January (where there is no difference). This anomaly should impact the Albedo derived products, even if the quantification of the error is not straightforward (e.g., the impact of a different solar illumination on TOC reflectance is function of the viewing geometry). As the SPOT/VEGETATION mission ended in May 2014, a full re-processing of the entire archive of TOA reflectances is planned. Once available, they will be used to re-generate the whole archive of SPOT/VGT GEOV1 Albedo products.

4 Reference Albedo Products

4.1 Product Description

In this section, the main features of the remote sensing albedo products investigated are described. A summary with their main characteristics can be found in Table 4.

Table 4: Characteristics of the global remote sensing 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.

Institution/Product	Sensor/Platform	GSD	Frequency	Composite Period(*)	Coverage	Projection	Reference
EC Copernicus GL GEOV1 AL_VGT	VEGETATION/SPOT	1 km	10-days	30-days (+12)	Global	Plate carrée	Geiger and Samain, (2004)
NASA / MCD43B3 C5	MODIS/TERRA+AQUA	1 km	8-days	16-days (+16)	Global	Sinusoidal	Schaaf et al., (2002)
CNES / POLDER3 Albedo	POLDER-3/PARASOL	6 km	10-days	29-days (+14)	Global	Sinusoidal	Lacaze & Maignan, (2010)
EUMETSAT / LSA SAF MDAL	SEVIRI/MSG	3 km	daily	5-days (-5)	MSG disk	MSG	Geiger et al., (2008)

4.1.1 NASA MODIS/Terra+Aqua

The MODIS BRDF/Albedo (MCD43B3) Collection 005, available since 2000 from https://lpdaac.usgs.gov, provides 1-kilometer data describing both directional hemispherical reflectance (black-sky albedo) at local solar noon and bihemispherical reflectance (white-sky albedo) for MODIS bands 1-7 as well as for three broad bands (VIS: 0.3-0.7µm, NIR: 0.7-5.0µm, and Total: 0.3-5.0µm). The MCD43B3 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. These MCD43B3 albedo quantities are produced from the 16-days BRDF model parameters product (MCD43B1). The Quality information is stored in the MCD43B2 product. Only those retrievals flagged as “best” or “good” quality were used. That means that at least 75% of the retrievals are qualified as “best full inversions” or “full inversions”.

The MODIS albedo algorithm uses atmospherically corrected reflectance data (MOD09 product) to establish the best fit to a linear kernel-driven BRDF model. Those observations flagged in MOD09 as “cloud”, “cirrus high” or “aerosol high” are removed. The parametric BRDF model uses the RossThick kernel for volumetric scattering and LiSparse-Reciprocal kernel for geometrical scattering (RTLSR) (Lucht et al., 2000). A full retrieval of RTLSR model is attempted if there are, during the 16-days synthesis period, seven or more high-quality observations well distributed over the viewing hemisphere. When the number of observations is less than 7 and greater than 2, or if observations are not well sampled or do not fit the BRDF model well, a backup algorithm with prior information is used. A fill value is stored if the number of observations is less than three. Then the BRDF model parameters are used for estimating spectral albedos from angular integration. The broadband albedos are computed using the spectral to broadband conversion approach developed by Liang et al., (1999).

Several validation studies of the MODIS albedo can be found in the literature. An accuracy of 0.013 was obtained comparing the combined Terra+Aqua albedo product with eight field stations during spring and summer months of 2003 and 2004 (Salomon et al., 2006). MODIS performed admirably over grasslands and shrublands. Accuracy dropped during the fall and winter months at some sites, probably as a consequence of a increased sub-pixel heterogeneity due to processes such as non-uniform patterns of snowmelt (Jin et al., 2003). An assessment of the Terra-only MODIS albedo product by Stroeve et al. (2005) concluded that MODIS albedos were largely accurate over regions of homogenous snow. MODIS Albedo has few high-quality retrievals over tropical forest (Gao et al., 2005) as cloud cover limits the number of looks available to the BRDF algorithm.

4.1.2 CNES POLDER-3 / PARASOL

The POLDER-3/PARASOL Land Surface Level 3 Albedo product, available since 2005 from http://www.theia-land.fr/en, provides data describing spectral directional hemispherical reflectance at solar noon and bihemispherical reflectance for 5 POLDER-3 bands as well as for two broad bands (VIS: 04-07 µm and Total: 0.4-4.0µm). Error estimates are associated to each albedo product. The POLDER-3 Albedo products are provided in the full resolution POLDER grid based on the sinusoidal equal area projection at 6 km spatial resolution (Lacaze, 2010). The temporal resolution is 10 days with a classical synthesis period of 30 days. The POLDER Level 3 Albedo product is derived from the Level 2 (cloud screened TOC reflectances) products. Validation results can be found in Hautecoeur and Roujean (2007), and Lacaze (2010b).
The POLDER-3/PARASOL Albedo algorithm is described in Lacaze and Maignan (2010). It relies on the inversion of a linear BRDF kernel-driven model. First, clouds are removed from TOA reflectance data taking advantage of the POLDER multi-spectral and multi-angular capabilities (Bréon and Colzy, 1999). Then, the TOA reflectance Level1 data is corrected from the effects of absorbing gazes, stratospheric and tropospheric aerosols to obtain the corresponding TOC reflectance (Level 2) data. Level 2 data is filtered to eliminate residuals and then used for the inversion of the BRDF model. A new linear kernel-driven BRDF model accounting for the hot spot effect is used (Maignan et al., 2004). This model combines the reciprocal geometric kernel of “Li_sparse” (Lucht et al., 2000) with the volumetric kernel of “Ross_thick” (Roujean et al., 1992) merged with a hotspot function (Bréon et al., 2002; Camacho et al., 2004). The modified linear model performs better than others, including the nonlinear model for the POLDER directional sampling (Maignan et al., 2004).The directional parameters of the BRDF model are used for computing directional albedo for the solar noon angle, and hemispherical albedo for a sun angle integrated over the day. Finally, the narrow to broadband albedo conversion is performed using the conversion coefficients specified by Météo-France/CNRM.

4.1.3 EUMETSAT LSA SAF SEVIRI/MSG

The LSA SAF (so-called Land-SAF) MSG Albedo product distributed by http://landsaf.meteo.pt/ since 2007 is generated on a daily basis at the spatial resolution of the MSG/SEVIRI instrument (3 km at nadir). An iterative scheme allows the composition of the information with a characteristic time scale of five days. The product contains the black-sky (at solar local noon) and white-sky albedos for the three shortwave SEVIRI channels (VIS 0.6µm, NIR 0.8µm, SWIR 1.6µm). In addition to the corresponding narrowband estimates, broadband albedo quantities are derived for the visible [0.4-0.7µm], near-infrared [0.7-4µm] and total shortwave [0.3-4 µm] ranges. The MSG Daily Albedo (MDAL) product is computed within the area covered by the MSG disk, over four specific geographical regions (Europe, North Africa, South Africa and South America). For each day and each geographical region the albedo quantities, their respective error estimates, and a quality flag are disseminated in HDF-5 format. Validation results and comparison with MODIS products can be found in Carrer et al., (2010) and, including comparisons with POLDER-3/PARASOL products, in the validation report (LSA-SAF, 2012).

The Land-SAF MSG albedo algorithm (Geiger et al., 2008) relies also on the inversion of a BRDF kernel-driven model. In a first step an atmospheric correction using the SMAC (Rahman and Dedieu, 1994) code is performed in order to derive top-of canopy (TOC) reflectance factor values each 15 minutes (i.e., SEVIRI image acquisition frequency) corresponding to the occurring sun view configurations. The cloud mask is generated in the system with the software provided by the SAF on Nowcasting and Very Short Range Forecasting. No real time information on aerosols is used, instead a constant value is assumed. In a second step the inversion of the Roujean et al., (1992) model is performed based on the available clear-sky observations accumulated during one day. In addition, constraints on the model parameters are taken into account in the inversion process. By specifying these constraints according to the previous model output in a recursive manner, a complete spatial coverage of the resulting MSG albedo maps is achieved. Finally, angular integration of the reflectance distribution delivers spectral albedo estimates, which are finally transformed to broadband albedo by applying suitable conversion relations (van Leeuwen and Roujean, 2002).

4.2 DIFERENCES IN THE ALBEDO RETRIEVAL

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.

TOC reflectance: To have best quality clear-sky TOC reflectance is necessary for estimating the albedo accurately. 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. This step of the albedo processing chain could introduce important discrepancies among the different products (e.g., see LSA-SAF, 2010). Note that the higher spatial resolution of MODIS should be better for detection of small clouds than coarser resolution sensors (SEVIRI, POLDER). Conversely, SEVIRI acquires a much large number of observations along the day increasing the probability to have clear-sky data. Note that the SEVIRI/MSG albedo algorithm uses a constant value of the aerosol optical thickness along the year and solely varies with latitude, which may introduce a non-negligible effect (Carrer et al., 2010).

BRDF model: GEOV1 and MSG use the Roujean et al., (1992) model. MODIS uses the Ross_Thick kernel (Roujean et al., 1992) for volumetric scattering and the LiSparse-Reciprocal kernel for geometrical scattering (Lucht et al., 2000). POLDER uses Maignan et al., (2004) model which combines the LiSparse-Reciprocal kernel for geometrical scatteringwith the volumetric kernel of Ross_Thick merged with a hotspot module (Bréon et al., 2002). Although the hotspot correction modifies the retrieved directional signature parameters, it does not change significantly the surface albedo (Maignan et al., 2004). Discrepancies between different albedo estimates are partly due to the different BRDF model used as shown in Carrer et al., (2010). Moreover, the performance of the BRDF model for good clear-sky observations will also depend of 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 characterisation (see Figure 3). MODIS and SPOT/VGT are wide-FOV sensors in polar orbiting platform that allows observing the surface under different sun-view configurations during consecutive tracks. SEVIRI is on-board a geostationary platform, and acquires a much frequent sampling (one image each 15 min) that allows to accumulate enough cloud-free observations along a single day for the BRDF model inversion. However, SEVIRI observes each surface target with a constant view zenith angle and the angular sampling comes from the illumination diurnal variations, whereas the multi-angular POLDER instrument provides a much better directional sampling in the observation geometry (up to 65º in the view zenith angle) as shown in Figure 3. Furthermore, the orientation of the CCD matrix in POLDER-3 is along-track increasing the number of observations up to 16 directions per track. Therefore, the POLDER-3 angular configuration is better to accurately reproduce the BRDF shape, especially in the principal plane direction where the directional variations are much higher. As a consequence, the BRDF/albedo retrieval should be more accurate. 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.

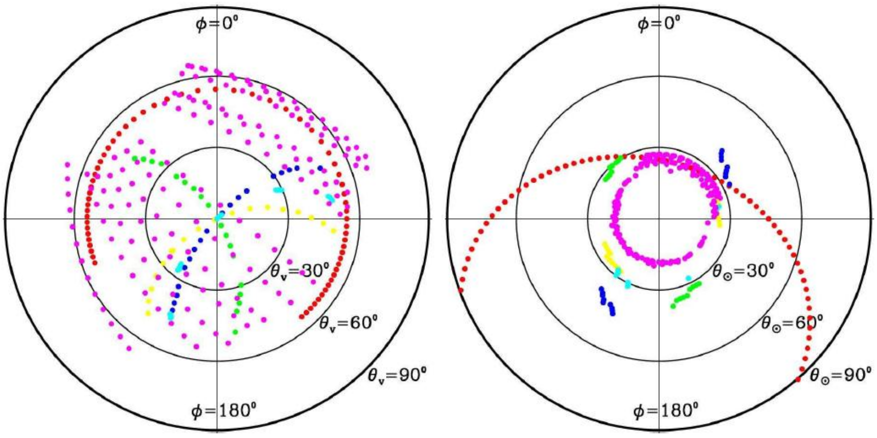


Figure 3: (Geiger and Samain, 2004): Observation (left) and illumination (right) geometries corresponding to a geographical location of [47° 47' N, 10° 37' E] and an observation period between the days of year 150 and 170. The colors of the dots denote observations taken by different sensors as follows: Red: SEVIRI/MSG, Green: AVHRR/METOP, Blue: AVHRR/NOAA, Yellow: MERIS/ENVISAT, Purple: POLDER1/ADEOS, Cyan: VGT/SPOT.

Compositing period: The compositing period of the different products is daily for the MSG product, 16-days for MODIS and monthly for GEOV1 and POLDER products although a different temporal weighting function is implemented in GEOV1 (near real time) and POLDER (maximum weight is put on the observations acquired in the middle of the compositing period) processing chains. The different compositing period could play an important role mainly in rapid albedo variations such as snow falling events. Monthly MODIS and MSG albedo products have been generated to minimise the impact of the different compositing period in the inter-comparison of products.

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. GEOV1 and MSG broadband albedos are ranging between 0.3 and 4 µm, POLDER between 0.4 and 4 µm, whereas MODIS ranges between 0.3 and 5 µm. No significant differences in albedo are expected due to the different spectral range used, but some differences may be associated to the narrow to broadband conversion. For instance, the use of a different method for narrow to broadband albedo conversion in MSG changed the sign of the bias between the MSG and MODIS visible broadband albedo (Land-SAF, 2010)

5 QUALITY ASSESSMENT METHOD

5.1 OVERVIEW

The validation procedure has been defined to be consistent with the best practices proposed by CEOS WGCV LPV subgroup. First, an inter-comparison with the existing global products (POLDER, MODIS) was performed to examine the spatial and temporal consistency of GEOV1 albedo products at global scales. Ground data from FLUXNET stations was used to evaluate the temporal realism of albedo seasonal variations. Second, a bulk statistical analysis over all BELMANIP-2 sites distributed around the globe for the considered 2006-2007 period was conducted and metrics were analysed as a function of the biome type. Third, a direct validation approach was conducted using ground data from FLUXNET stations to quantify the accuracy of the products. Finally, a regional assessment over Europe and part of Africa was conducted including MSG Albedo products for the year 2007.

To compare satellite products a similar spatial support area and temporal support period must be defined. Therefore, the spatial sampling was modified to get similar spatial support across all the products investigated. The products were re-sampled over a common Plate Carrée projection at 6 km spatial sampling grid (i.e., POLDER spatial resolution). This spatial resolution allow to reduce co-registration errors between 1-km products and inconsistencies associated to differences in the point spread function of the re-projected products (Weiss et al., 2007). For 1-km resolution products (MODIS, GEOV1), the re-sampling was done only when the percentage of 'best quality' pixels within the 6x6 km^2 region was higher than 75%. This 6-km grid spatial support used to inter-compare all albedo products under study will be later called minimum consistent spatial support (MCSS).

To better compare the products, a common temporal support period (CTSP) should be also considered. The 10-days temporal frequency of POLDER and GEOV1 was selected. Each GEOV1 albedo date was compared with the closest POLDER-3 albedo product, and only minor differences remains due to the different temporal weighting scheme. Regarding MODIS, a weighted average of three consecutive 8-days products was computed. For comparisons with GEOV1 the higher weight (0.5) was given to the last date, whereas for comparisons with POLDER the higher weight was given to the central date. For Land-SAF MSG daily product a monthly average considering temporal weighting function was computed from daily observations.

Several criteria of performance were assessed in agreement with previous global validation exercises (eg. Weiss et al., 2007; Garrigues et al., 2008; Camacho et al., 2011) and users' requirements. Discrepancies between low resolution products were quantified by the correlation coefficient (R^2), the systematic bias (mean values of the differences, i.e. mean accuracy), the root mean square error (RMSE = total error, i.e. overall performance) and the root mean square error (RRMSE, %) relative to the mean value of the two compared products.

Methods, sampling strategy and metrics are presented below for each of the criterions considered in the validation protocol (sections 5.2 to 5.7).

5.2 SPATIAL AND TEMPORAL CONTINUITY

It represents the fraction and distribution in space and time of the missing data (gaps), mainly due to clouds, poor atmospheric conditions or technical problems during the acquisition of the images. This criterion has been identified as very important by the users. The fraction of missing data was computed and analyzed as a function of time and latitude. The MCSS was used, and all the data available during the period was used. In addition to the invalid or out of range values, the following quality flag information (Table 2) has been used in the whole study to select best quality retrievals.

Table 5: Quality flag information used to filter low quality or invalid pixels.

Product	Quality flag
GEOV1	Sea (bit 1), Input status out of range or invalid (bit 6), AL-XX-YY out of range or invalid (bits 7,8,9), B2 saturated (bit 10), B3 saturated (bit 11)
MCD43B2	Albedo Ancillary bits 04-07: Shallow ocean, ocean and lake shorelines, shallow inland water, ephemeral water, deep inland water, moderate or continental ocean, Deep ocean. Albedo Band Quality: Mixed 50% or less full inversions and 25 % or less fill values (bit 2), All magnitude inversions or 50% or less fill values (bit 3), 75% or more fill values (bit 4)
MSG	Ocean, Space and Continental water (bits 0-1), No MSG observations (bit 2), No external information (bit 4), Algorithm Failed (bit 7).

5.3 SPATIAL CONSISTENCY

The global maps of products were generated and analyzed to investigate possible patterns specific to a given product as well to check the spatial consistency through visual analysis (artefacts corresponding to tiles, stripes, presence of outliers). To evaluate globally the spatial consistency of the several albedo products difference maps between pairs of products were computed, as well as the mean difference (mean bias error, B) along the period.

5.4 TEMPORAL CONSISTENCY

The temporal profiles observed over a sample of about 470 sites from BELMANIP-2, FLUXNET and additional snow/ice sites were analyzed to qualitatively assess the temporal consistency between the several products considered. The realism of the seasonal variations of albedo, with attention to the short-term variations (e.g., snow falling or melting) was investigated in a few number of homogeneous FLUXNET sites were ground albedo data was available for the investigated period. Moreover, the reliability of the SPOT/VGT albedo error bar was discussed by considering the uncertainty introduced by the different remote sensing product albedo estimations and the ground reference values.

The smoothness is a major component of the temporal consistency as a measure of the short time stability. As a matter of fact, high temporal smoothness is expected for these albedo variables that change through incremental processes (except in the case of snow falling events or disturbance). It was 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:

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

Note that the original temporal sampling of the products was kept were the MCSS was used.

Finally, the temporal variations of albedo products were checked over 20 desert sites in Sahara and Arabia. These reference sites, well known for their high temporal stability, are used by CNES for the absolute calibration of remote sensing sensors. Therefore, scatter plots between two consecutive years were analyzed to evaluate the precision of the albedo products over these highly stable sites.

5.5 GLOBAL STATISTICAL ANALYSIS

Because the spatial and temporal consistency evaluation presented before is rather qualitative a more comprehensive and quantitative analysis is required. It is conducted over the whole common time period available and for a globally representative set of sites. The BELMANIP-2 network of sites (Figure 3) designed to represent globally the variability of land surface types was used here. It is an improved version of the original BELMANIP sites (Baret et al., 2006). To allow comparison between the products, the same temporal (10-days) and spatial (6x6 km2) supports were used.

The distribution of products values is then generated in the form of PDFs (Probablity Density Function). Discrepancies are further quantified based on metrics associated to the scatter plots between pairs of products (i.e., correlation, bias, root mean square error), and the temporal variation of metrics is analysed. These analyses are achieved per aggregated land cover class based on the 7 generic classes derived from the GLC-2000 classification (Bartholomé and Belward, 2005): Broadleaf Evergreen Forest (BEF), Broadleaf Deciduous Forest (BDF), Needle leaf Forest (NLF), Shrublands (S), Herbaceous (H), Cultivated (C), Sparse and Bare areas (SBA). An additional set of locations over latitudes beyond 60ºN and the Antartic region region was selected to analyse discrepancies over Snow/Ice land pixels.

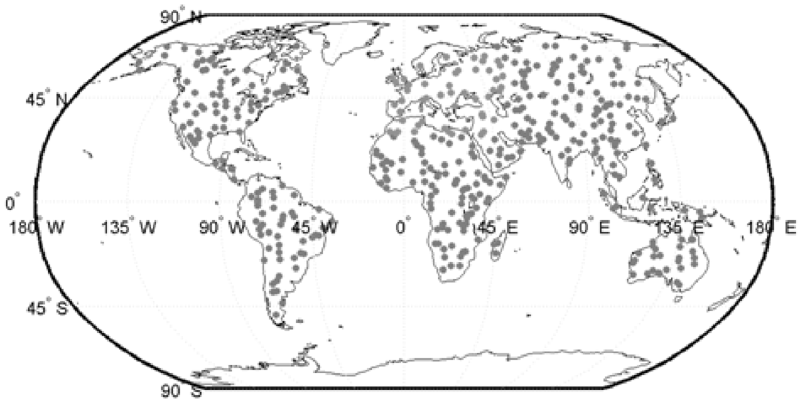


Figure 4: Location of the 420 BELMANIP-2 sites over the globe

5.6 DIRECT VALIDATION

Quantitative uncertainties of SPOT/VGT Albedo products were computed against ground reference data from FLUXNET stations. The scattering is carried out by compositing the daily field data at noon over the compositing period of the satellite product. The different temporal compositing weighting scheme was considered for each product. A composite value is obtained when more than 50% of daily measurements are available. For inter-comparison with MODIS and POLDER products the MCSS was used, considering only the coincident observations during the period. We used only those sites where the albedo at 6 km shows no significant deviations regarding the estimate at 1 km. From the field measurements snow events were identified and flagged in order to be able of estimating the accuracy for snow-free observations.

FLUXNET is a global network of regional networks (eg. CarboeuropeIP, AmeriFlux, or Fluxnet-Canada) of micrometeorological tower sites that uses eddy covariance methods to measure the exchanges of carbon, water and energy fluxes between ecosystem and atmosphere. In February 2007, at the La Thuile workshop, scientists began to assemble a world-wide carbon-climate field dataset into the La Thuile 2007 Synthesis Data. This dataset is expected to expand each year as new data are taken and new sites are deployed. The Global FLUXNET Synthesis Data Server is available at http://www.fluxdata.org.

Field measurements however represent point measurements on the ground and are not easily comparable to the satellite kilometric pixel data unless the assumption of homogeneity of the land surface is made. Therefore, direct comparison can be performed only under very homogeneous sites (Roman et al., 2009). A selection of homogeneous FLUXNET sites from La Thuile 2007 synthesis database was provided by Alessandro Cescatti (JRC) which can be used for direct comparison with satellite data (Table 6). These sites were used for assessing the temporal realism of SPOT/VGT albedo products.

For accuracy assessment we need the "blue-sky albedo", which can be estimated from the DHR and BHR satellite product values weighted by the fraction of direct and diffuse down-welling shortwave radiation, respectively. Only in four homogeneous sites diffuse radiation was available for the year 2006 (Table 7), but only three of them were found adequate for comparisons at 6-km.

In order to increase the number of sites up to eight a different period (2003-2004) was used to validate SPOT/VGT albedo products at 1 km spatial resolution.

Table 6: Homogeneous FLUXNET sites (La Thuile 2007 database) with field albedo measurements.

	SITE	COUNTRY	NAME	Land Cover	Lat (deg)	Lon (deg)
1	AU Tum	Australia	Tumbarumba	Broadleaved Evergreen Forest	-35,66	148,15
2	AU Wac	Australia	Wallaby Creek	Broadleaved Evergreen Forest	-37,43	145,19
3	DE Geb	Germany	Gebesee	Cultivated	51,1	10,91
4	DE Hai	Germany	Hainich	Broadleaved Deciduous Forest	51,08	10,45
5	DE Kli	Germany	Klingenberg	Cultivated	50,89	13,52
6	DE Tha	Germany	Tharandt-Anchor Station	Needle-leaved Forest	50,96	13,57
7	DE Wet	Germany	Wetzstein	Needle-leaved Forest	50,45	11,46
8	ES ES2	Spain	El Saler-Sueca	Cultivated	39,28	-0,32
9	ES LMa	Spain	Las majadas del Tietar	Herbaceous	39,94	-5,77
10	FR Fon	France	Fontainebleau	Broadleaved Deciduous Forest	48,48	2,78
11	FR Hes	France	Hesse Forest-Sarregourg	Broadleaved Deciduous Forest	48,67	7,07
12	FR Pue	France	Puechabon	Broadleaved Evergreen Forest	43,74	3,6
13	GF Guy	French Guiana	French Guiana	Broadleaved Evergreen Forest	5,28	-52,93
14	HU Bug	Hungary	Bugacpuszta	Herbaceous	46,69	19,6
15	IT Bon	Italy	Bonis	Needle-leaved Forest	39,48	16,54
16	IT Col	Italy	Collelongo-Selva Piana	Broadleaved Deciduous Forest	41,85	13,59
17	IT SRo	Italy	San Rossore	Needle-leaved Forest	43,73	10,29
18	KR Kw1	Korea	Gwangneung	Broadleaved Deciduous Forest	37,75	127,16
19	NL Ca1	Netherlands	Cabauw	Cultivated	51,97	4,93
20	NL Lan	Netherlands	Langerak	Cultivated	51,95	4,9
21	NL Loo	Netherlands	Loobos	Needle-leaved Forest	52,17	5,74
22	PT Esp	Portugal	Espirra	Broadleaved Evergreen Forest	38,64	-8,6
23	US Aud	USA	Audubon Research Ranch	Herbaceous	31,59	-110,51
24	US Bo1	USA	Bondville	Cultivated	40,01	-88,29
25	US Bo2	USA	Bondville	Cultivated	40,01	-88,29
26	US Fmf	USA	Flagstaff - Managed Forest	Needle-leaved Forest	35,14	-111,73
27	US FPe	USA	Fort Peck	Herbaceous	48,31	-105,1
28	US Fuf	USA	Flagstaff - Unmanaged Forest	Needle-leaved Forest	35,09	-111,76
29	US IB1	USA	Fermi National Accelerator Lab.	Cultivated	41,86	-88,22
30	US Ivo	USA	Ivotuck	Shrublands	68,49	-155,75
31	US MOz	USA	Missouri Ozark	Broadleaved Deciduous Forest	38,74	-92,2
32	US SRM	USA	Santa Rita Mesquite	Shrublands	31,82	-110,87
33	US WCr	USA	Willow Creek	Broadleaved Deciduous Forest	45,81	-90,08

Table 7: Homogeneous FLUXNET sites with field albedo and fraction of diffuse radiation measurements

Site	Country	Name	Period	Lat (deg)	Lon (deg)	Land Cover
AU-Wac	Australia	Wallaby Creek	2005-2007	-37,43	145,19	BEF
CA-Ca1	Canada	Campbell River 1949 Douglas-fir	2000-2005	49,87	-125,33	NLF
CA-Ca3	Canada	Campbell River 1988 Douglas-fir	2002-2005	49,53	-124,9	NLF
CA-Wp1	Canada	Western Peatland Canada	2003-2005	54,95	-112,47	NLF
CZ-Bk1	Czech Republic	Bily Kriz - Beskidy Mountains	2000-2005	49,5	18,54	NLF
DE-Geb	Germany	Gebesee	2004-2006	51,1	10,91	C
DE-Hai	Germany	Hainich	2000-2006	51,08	10,45	BDF
DE-Wet	Germany	Wetzstein	2002-2006	50,45	11,46	NLF

5.7 REGIONAL ASSESSMENT

A special focus of the consistency between remote sensing albedo products, including also the Land-SAF MSG product, over a large region (40ºx40º) covering Europe and part of North Africa (Figure 4) is finally presented. This region presents very different climatic conditions and a variety of biomes from desert to boreal forest. The dominant classes are Cultivated (38.9%) and Bare Areas (37.2%). The same spatial and temporal supports as in the global analyses were used. Difference maps were displayed; scatter plots and performance metrics per main biome type were computed but now considering all best-quality "homogeneous" pixels regarding land cover type (i.e., all 1-km pixels within the 6-km grid belong to the same GLC-2000 category). The analysis was done for the year 2007.

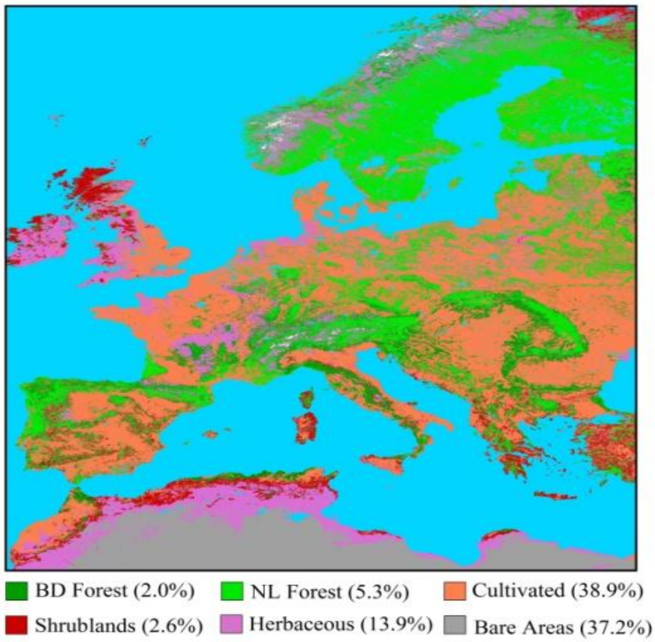


Figure 5: Map of six biomes over the selected window for the regional assessment

6 RESULTS

6.1 SPATIAL AND TEMPORAL CONTINUITY

Figure 6 displays global maps of the percentage of missing values during the 2006-2007 period for the albedo products. The information provided by two fields of the quality flag (QF) is displayed in Figure 7. Pixels flagged as invalid values or low quality in the QF (see Table 5) are considered here as missing values too. The same results are obtained for the different albedo products as no observations were discarded due to out-of-range albedo status (bit 7 (VIS), bit 8 (NIR) or bit 9 (BB)).

The spatio-temporal continuity of the SPOT/VGT Albedo product is poor over latitudes higher than 45º North and over the equatorial belt. The main reason should be the lack of clear-sky observations due to persistent cloud coverage over these regions. The SPOT/VGT QF information has been analysed to know which factors are responsible of missing or invalid values. Figure 7 shows the percentage of gaps due to the input status (bit 6) and the B0 saturation (bit 11). The input status displays an important fraction of out of range or invalid values during the period in the problematic areas (Northern latitudes, equatorial belt). On the other hand, the saturation of B0 data is important only over high latitudes (>60ºN).

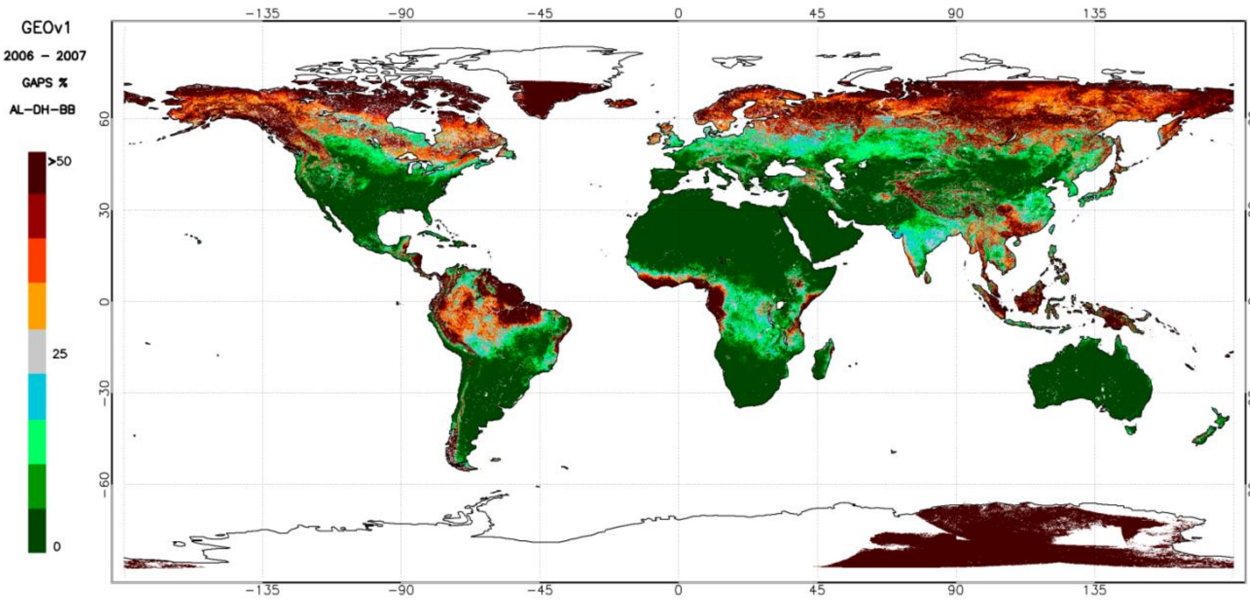


Figure 6: Percentage of missing values during the 2006-2007 period.

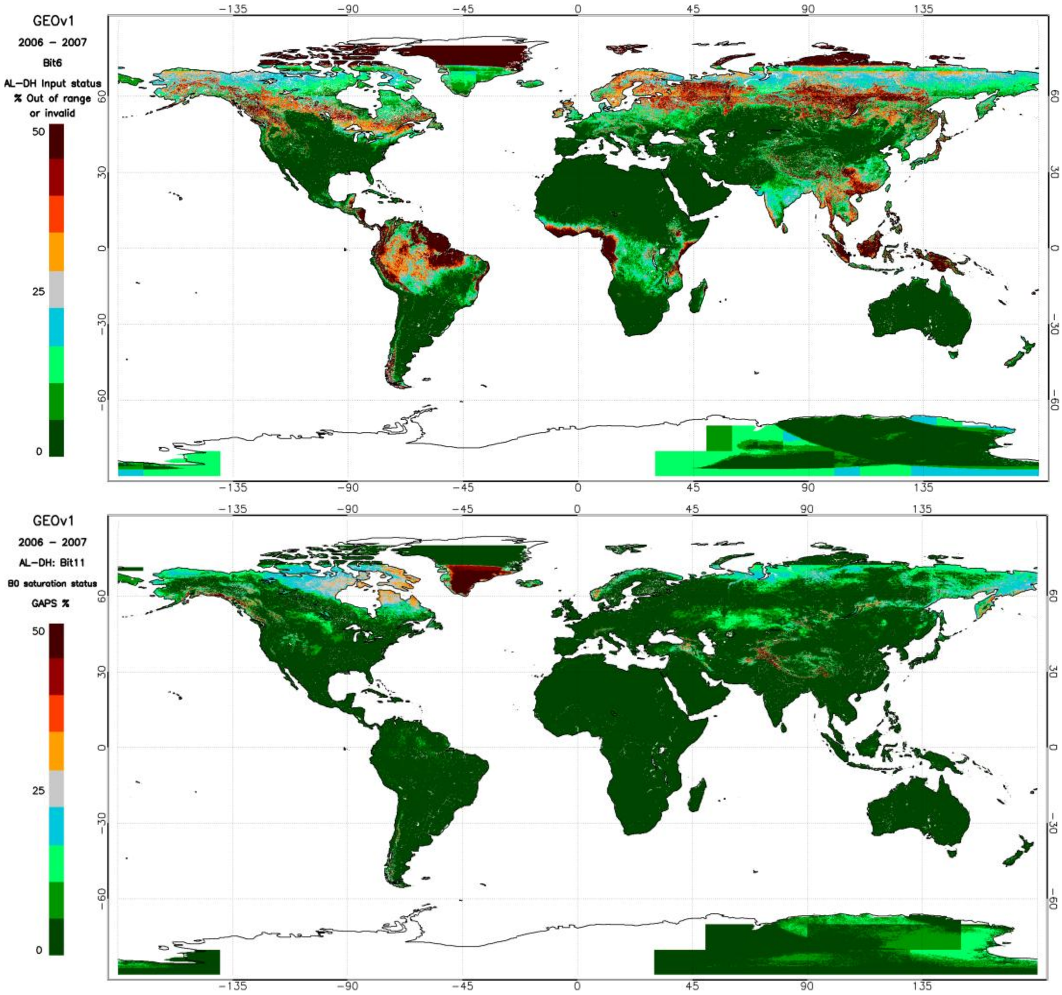


Figure 7: Percentage of observations flagged as invalid during the 2006-2007 period according to the Quality Flag information of AL-DH for input status (top) and B0 saturation (bottom).

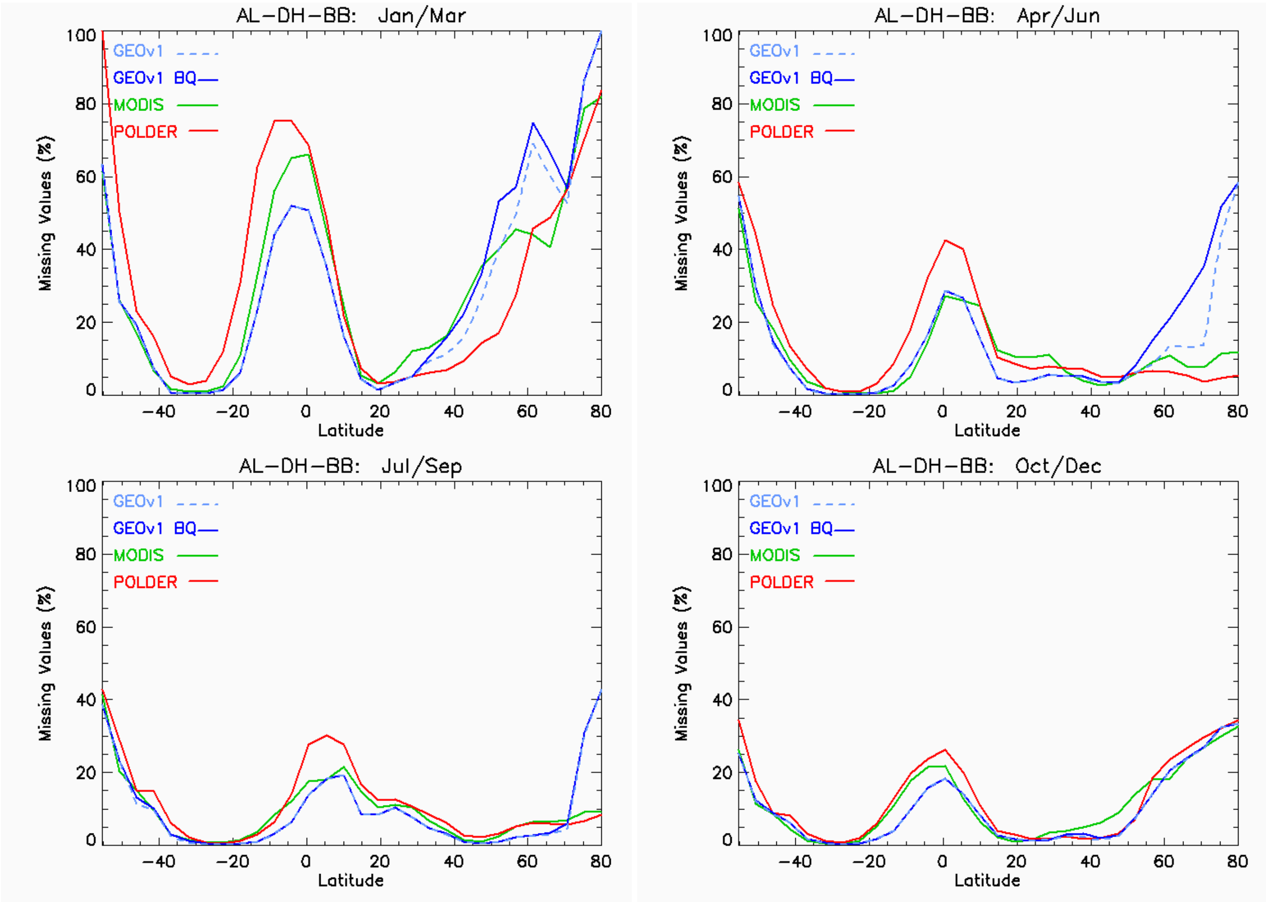


Figure 8: Percentage of missing values over land pixels as a function of latitude and period. Here, GEOV1 refers to missing values in the product field, and GEOV1-BQ to missing values including the quality flag information.

Figure 8 shows the fraction of missing data according to the QF information (Table 5) as a function of time and latitude. Very similar results are obtained for the three other polar-orbiting satellite-based albedo products with a peak around the equator (up to 80% of missing values in the period January to March) and for higher latitudes. The fraction of missing values presents a high dynamic as a function of the period of the year, with very low fraction of good observations during the January to March period in the northern hemisphere. In this period, GEOV1 has better continuity over the equatorial band, but lower continuity over northern latitudes. Conversely, POLDER has lower continuity over equatorial belt as expected for its lower spatial resolution under persistent cloud conditions; however has better continuity than SPOT/VGT or MODIS over northern latitudes (30º-70º) during winter. Note that for MODIS only best quality data was considered according to the quality flag, whereas PARASOL does not provides a quality flag. It is noticeable that during the April to June period, the GEOV1 SPOT/VGT products present a much larger fraction of missing values over northern hemisphere than POLDER or MODIS products, even more when the quality flag is used to remove albedo values retrieved using suspicious input data (GEOV1BQ). The difference is more evident during spring when it can be found mixed snow/vegetation pixels at highest latitudes. One tentative explanation is that the inversion process of GEOV1 algo (which allows to get very smooth profiles) removes data which are far from the model (see figure 2 of the PUM), and the model cannot simulate properly mixed snow/vegetation BRDF. Then, the filtering removes too much acquisitions and it does not remain enough data to perform the final inversion. Note also that the use of the QF (bit 6) introduces a significant fraction of missing values around 50-70º N mainly in April/June period (see GEOV1 BQ), which mainly affects to pixels under snow conditions. These retrievals however were found reliable over the BELMANIP-2 sites.

In summary:

The spatial continuity of SPOT/VGT albedo products fails over some regions and periods. This constitutes a strong drawback for using these products mainly over northern latitudes in winter time, as in the other polar-orbiting products, where the surface albedo may present larger temporal variations due to changes in the snow cover.

The use of the QF (input status) removes a significant fraction of retrievals between 50º-70ºN mainly in spring time. These retrievals however were found consistent with those not flagged as invalid, and could be considered with caution.

6.2 SPATIAL CONSISTENCY

The reliability of the spatial distribution of GEOV1 retrievals was evaluated against existing products. Maps of the mean difference of shortwave directional albedo products along the period are shown in this section. Very similar results were found for the white-sky albedo (see Annex A for all the albedo products).

A very good spatial consistency was found between SPOT/VGT and MODIS shortwave directional albedo products (Figure 9), showing slight systematic differences except in Greenland and Antarctic. GEOV1 albedo shows slight higher values than MODIS in large regions of Europe, North and West Africa and South and East Asia. Conversely, MODIS provides in average higher values over very high latitudes (>60º) where the presence of snow becomes more important. The spatial distribution of the differences between SPOT/VGT and MODIS broadband albedo quantities changes for the other regions, mainly for the NIR region where MODIS albedo is higher for equatorial forest and desertic regions (see Annex A).

POLDER shortwave black-sky albedo presents higher values than GEOV1 over almost the whole global map (Figure 10), whereas SPOT/VGT albedo is higher over the Sahara and Arabic deserts. Mean differences are generally between ±0.025 units, with larger differences in equatorial and boreal regions. The largest discrepancies (up to 0.1) appear for the Tibetan Plateau and the polar regions. For the PAR domain, POLDER black-sky albedo is higher than GEOV1 all around the globe. Same results are found for the white-sky albedos (see Annex A).

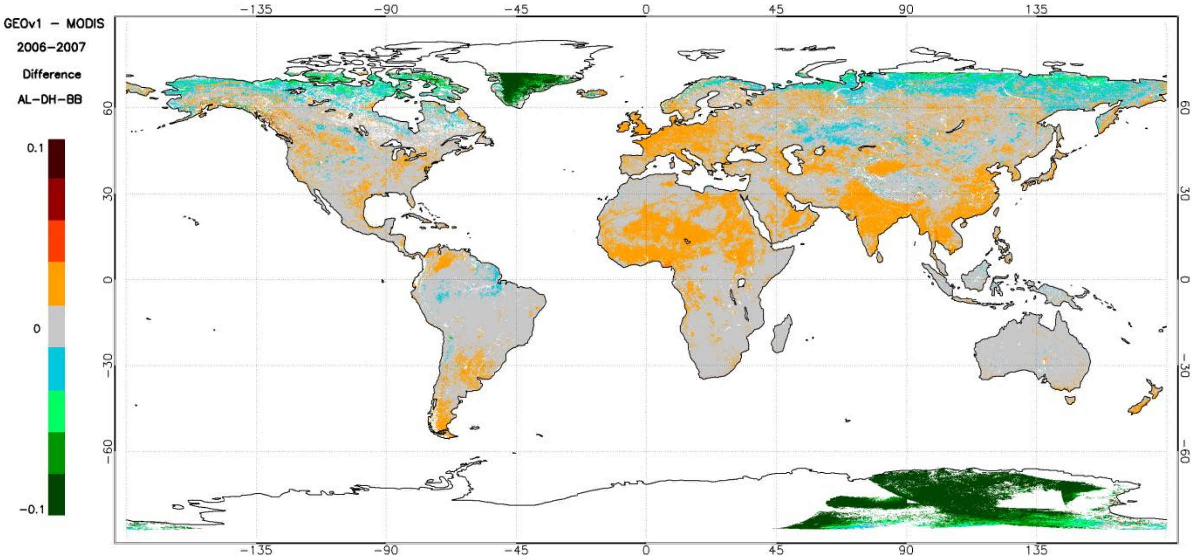


Figure 9: Mean differences between SPOT/VGT (GEOV1) and MODIS shortwave directional albedo products during the 2006-2007 period.

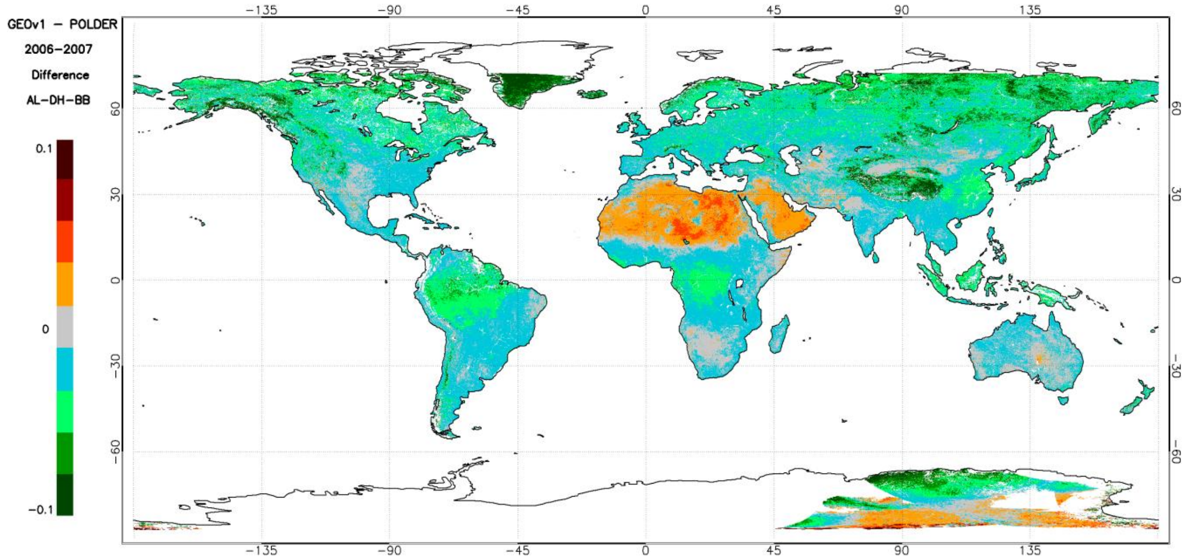


Figure 10: Mean differences between SPOT/VGT (GEOV1) and POLDER shortwave directional albedo products during the 2006-2007 period.

POLDER shortwave directional albedo present higher values than the equivalent MODIS product in most regions (Figure 11), with differences around 0.05 over equatorial regions, Europe and East-Asia, and the highest differences (up to 0.1) for the Tibetan Plateau and the Boreal Region (Canada, Siberia). Conversely, MODIS directional albedo is slightly higher over deserts (Sahara, Arabian, Australia) (as reported in Lacaze, 2010b), and regions with permanent snow/ice cover (Greenland, Antarctic). For the PAR albedo, similar results were obtained except for Deserts were POLDER PAR directional albedo is much higher than the MODIS similar product (Annex A). The bi-hemispherical reflectance products show the same spatial consistency features than directional albedo products.

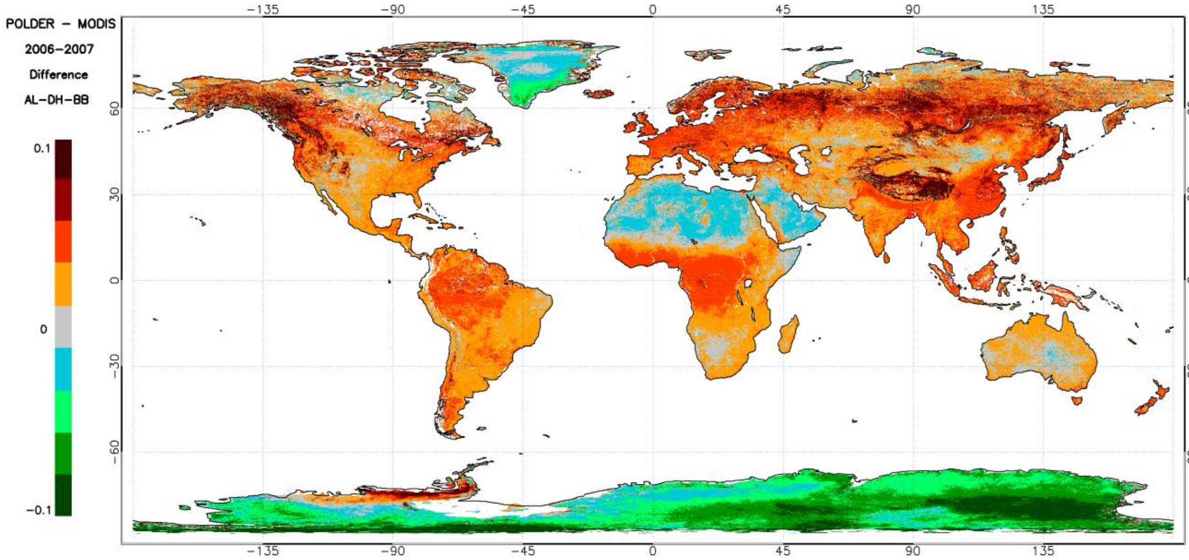


Figure 11: Mean differences between POLDER and MODIS shortwave directional albedo products during the 2006-2007 period.

In summary,

SPOT/VGT and MODIS albedo products show very consistent spatial distribution of retrievals over the globe. The main observed discrepancy is over boreal or polar areas where snow's albedo plays a major role.

The comparison with POLDER-3 shows larger spatial discrepancies, mainly over the equatorial belt and the boreal region, the Tibetan Plateau and over deserts (mainly Sahara and Arabian). Higher albedo values are provided by POLDER, except over desertic regions (SPOT/VGT and MODIS albedo values are higher) and the Polar Regions (MODIS higher). For the visible albedo, POLDER-3 albedo quantities are higher also over the arid regions.

6.3 Temporal Consistency

6.3.1 Temporal Variations

Temporal profiles of the different products under study were analyzed over BELMANIP-2 and FLUXNET sites where ground data for the considered period was available. To evaluate the temporal realism of profiles the available blue-sky albedo ground data was also displayed.

Figure 12 shows some examples over FLUXNET and BELMANIP-2 validation sites (including MSG values). All the remote sensing albedo products display very consistent temporal profiles. The remote sensing products reproduce generally well the strong albedo variations due to persistent snow (eg., Shrublands, Cultivated). However, GEOV1 was not able to capture properly spurious (few dates) snow event (e.g., US Fmf) or present a large amount of missing values over snow (e.g., US Iva), which may be explained due to the applied procedure to remove outliers in the compositing period [see GIOGL1_ATBD_TOC-r]. Note that the snow event of US Ba1 is well captured in the product field, but however these retrievals are flagged as invalid input (in light blue color). Many sites displayed very stable albedo retrieval over a period of time (e.g., US SRM).

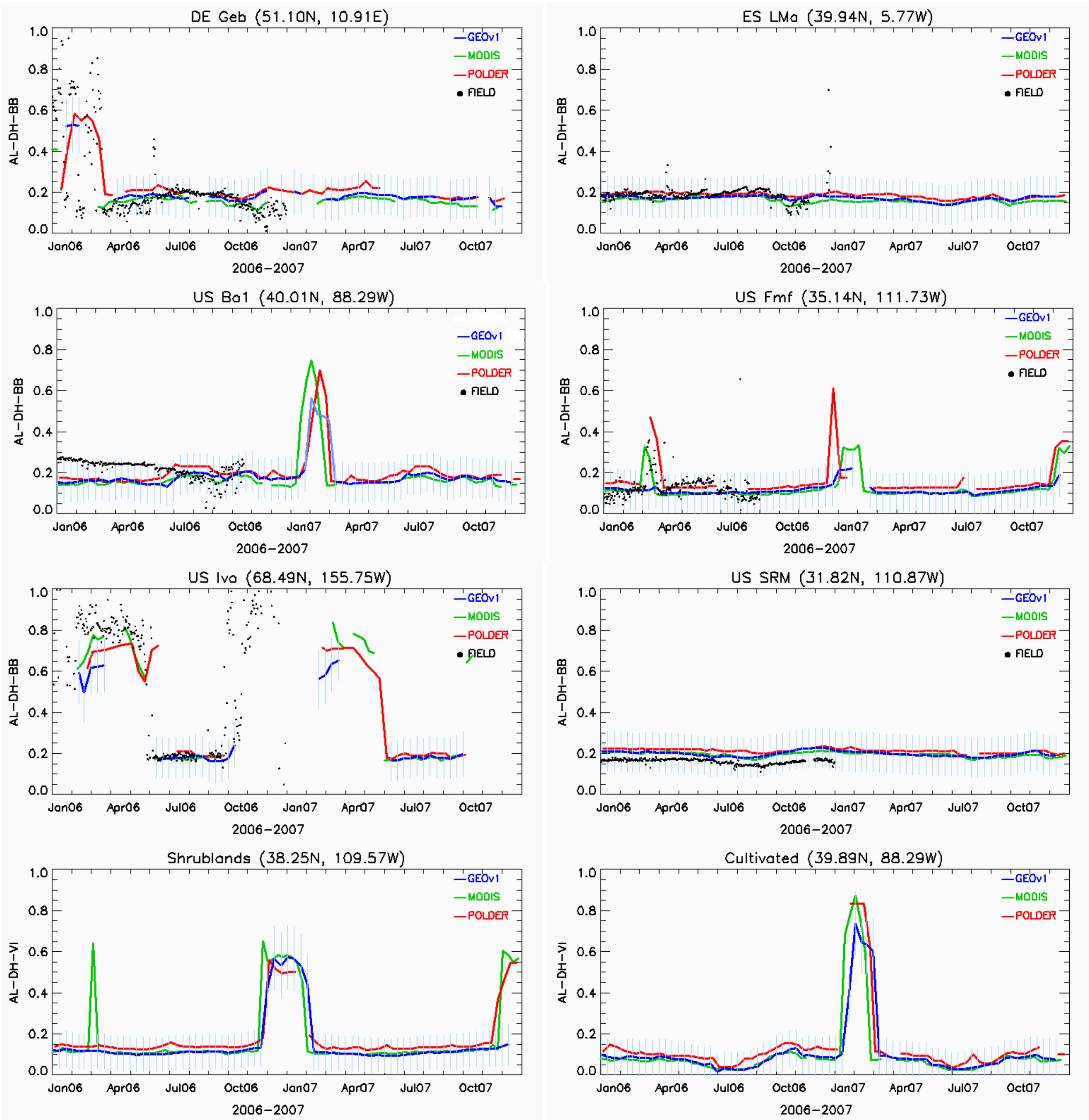


Figure 12: Temporal profile of SPOT/VGT (GEOV1), MODIS and POLDER-3 black-sky albedo (AL-DH-BB) over several FLUXNET and BELMANIP sites. Vertical bars for GEOV1 products correspond to the error estimate.

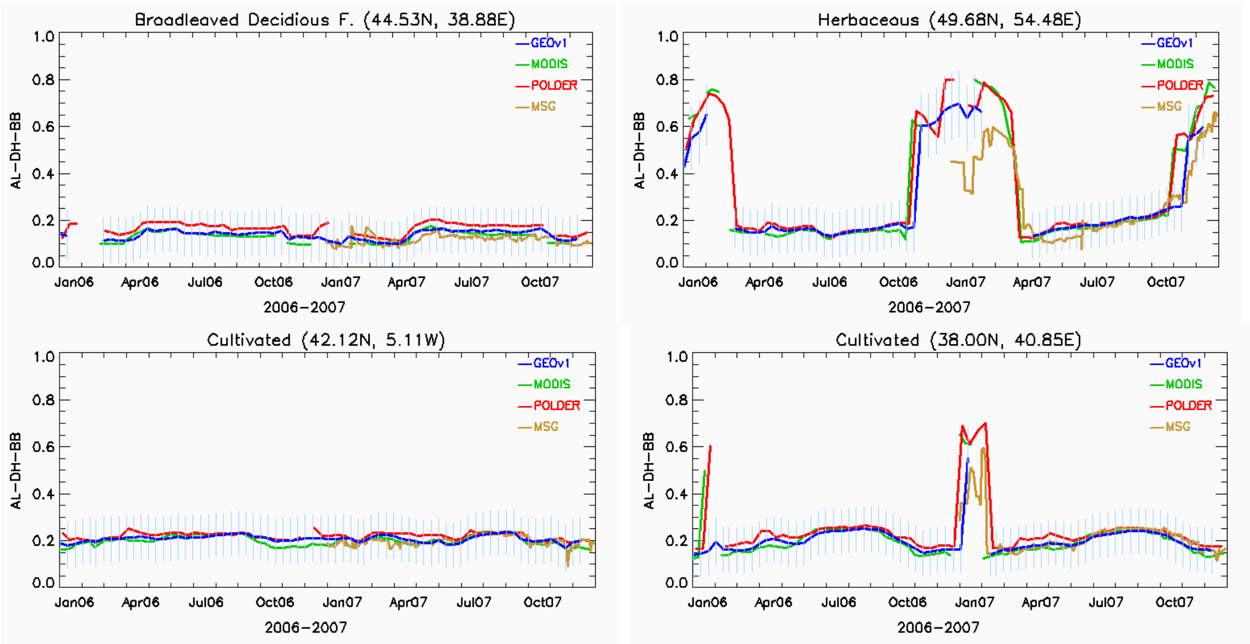


Figure 12 (cont). Temporal profiles including MSG black-sky albedo (AL-DH-BB) values over several BELMANIP sites.

The temporal profiles of GEOV1 are displayed with vertical error bars which correspond to the error provided with the product. The error bar is typically of ±0.1 for albedos lower than 0.2. This is a large uncertainty for the albedo estimate. If we assume that the uncertainty of the remote sensing estimates may be also quantified by the uncertainty existing among the different albedo products, we should conclude that the error bar of GEOV1 is unreliable, except probably over snow targets.

The temporal smoothness and precision of the products is quantified hereafter.

6.3.2 Smoothness

Figure 13 shows the histograms of the smoothness (δ) for the directional albedo in the total shortwave and visible spectral ranges. 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. The higher δ values of POLDER-3 albedo products in the PAR domain can be partly explained by the higher values of the retrieved albedo mainly over Forest sites (see Section 6.4).

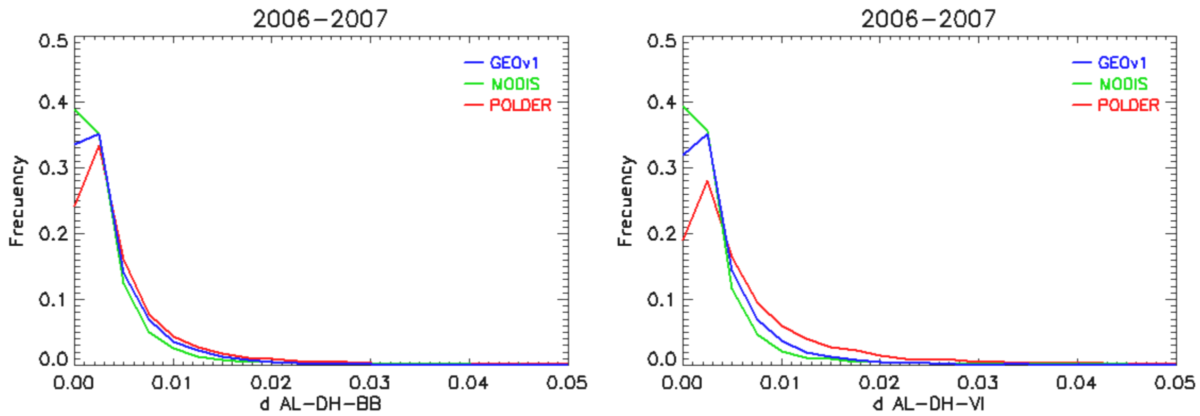


Figure 13: Temporal smoothness (dAL) distributions for directional albedo (AL-DH) products in the total shortwave (left panel) and visible broadbands (right panel).

6.3.3 Precision

First, the temporal variations over the calibration desert sites are shown in Figure 14. Some discrepancies are observed in the seasonal behavior. GEOV1 depicts a clear seasonality with maximum black-sky albedo values during winter (i.e., lower sun zenith angles). Black-sky albedo displays a typical bowl-shape as a function of the solar zenith angles, with lower values (higher absorption) for lower zenith angles (Liu et al., 2008). The amplitude of this seasonal variation is lower in MODIS or POLDER. The larger amplitude of GEOV1 Albedo should be partly explained as a consequence of the incorrect implementation of the standardization of solar illumination in VGT-P products. On the other hand, MSG albedo displays a high temporal stability over desert. The different angular sampling used for the BRDF characterization between polar-orbiting products based on viewing variations and MSG based on diurnal reflectance variations could be behind this different temporal behavior.

To quantitative determine the precision of the global albedo products, scatter plots and metrics between the albedo values of the two consecutive years were generated (Figure 15). The three global products examined shows highly precise retrievals, with systematic deviations from one year to another below 0.002 (GEOV1 below 0.001), and RMSE values below 0.008. This demonstrate over almost “invariant” sites that the albedo estimates are highly precise, and very low uncertainties are introduced in the processing chain over cloud free sites.

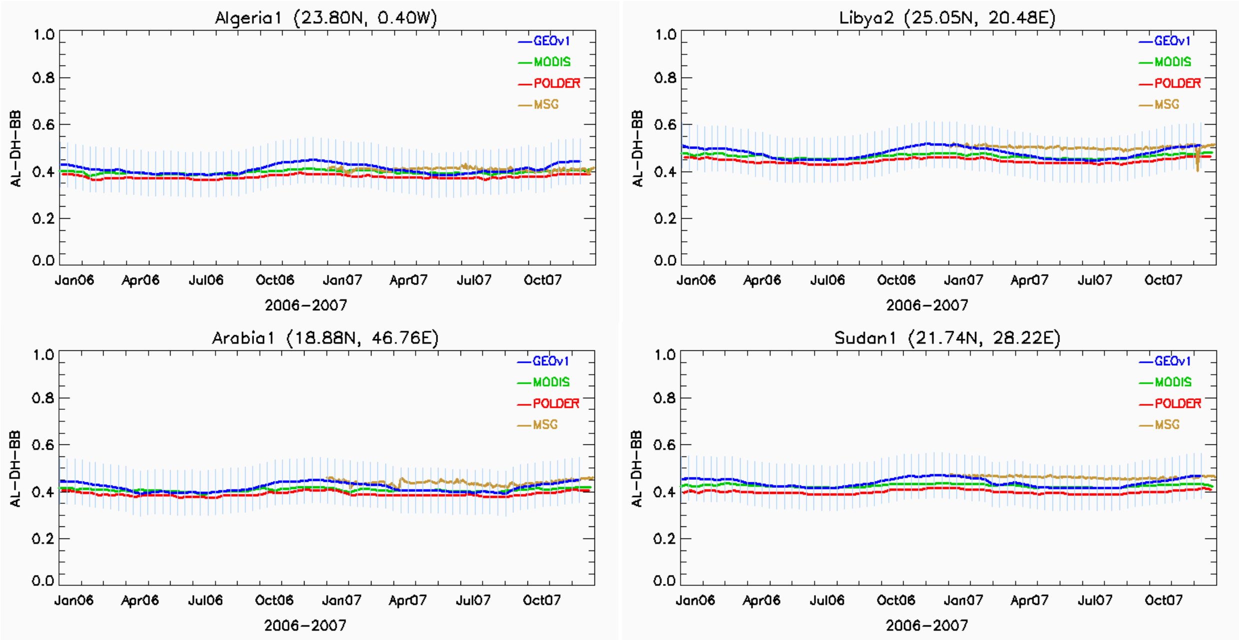


Figure 14: Temporal profile of SPOT/VGT (GEOV1), MODIS, POLDER-3 and MSG black-sky albedo (AL-DH-BB) over several desertic sites used for sensor calibration. Vertical bars for GEOV1 products correspond to the error estimate.

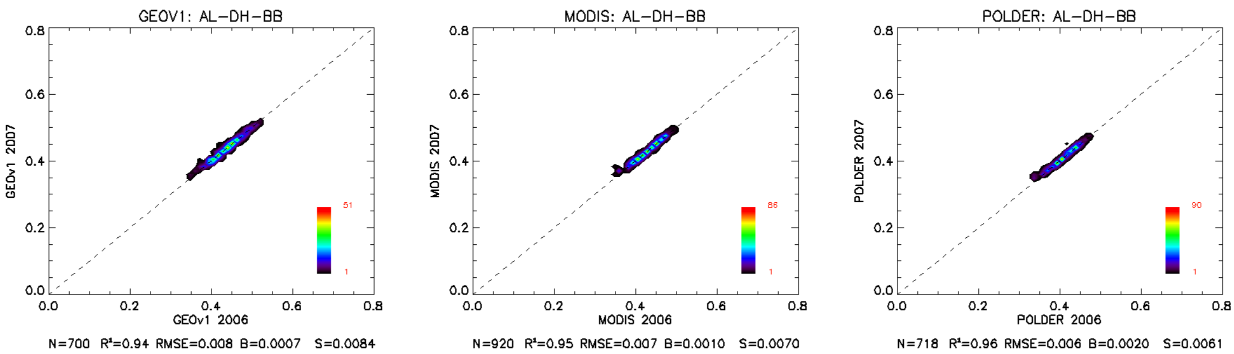


Figure 15: Directional-Hemispherical reflectance (AL-DH) product year 2006 versus year 2007 scatter plots over calibration sites for GEOV1 (left), MODIS (center) and POLDER (right). The terms B and S represent the mean and the standard deviation of the difference between the black-sky albedo products shown in the axes.

In summary,

GEOV1 provides reliable temporal variations, consistent with other products and ground data, that reproduces generally well strong changes due to snow falling or melting. However, over very stable calibration desert sites, GEOV1 profiles display larger seasonal variations than reference products. This larger amplitude in albedo seasonal variations should be partly explained due to the impact of the incorrect standardization of solar illumination in the VGT input data.

As compared with the other satellite products, GEOV1 fails to detect spurious snow events. The number of missing values over snow events is also larger for GEOV1, mainly when additional observations are removed according to the QF information.

The error bars of SPOT/VGT are larger than the uncertainty level associated to different remote sensing estimates, and probably overestimate the actual uncertainty of the albedo estimate in most situations except for snow targets.

The temporal profiles are very smooth, and the precision of retrievals over calibration sites was better than 0.008 units.

6.4 GLOBAL STATISTICAL ANALYSIS

This section provides the global statistical analysis over BELMANIP-2 sites along the 2 years period at a 10-day frequency. Histograms and statistics are provided per biomes.

6.4.1 Scatter Plots between Pair of Products

Figure 16 shows product versus products scatter plots for the black-sky albedo products in the PAR and shortwave domains. GEOV1 and MODIS products present a very good performance, with overall discrepancies of about 0.02/0.04 units for the shortwave/PAR domain, and no systematic differences except for snow albedo values. The scatter plots with the POLDER-3 albedo are characterised by the systematic bias mainly for low albedo values. Both, SPOT/VGT and MODIS directional albedos are systematically lower than the POLDER estimate, with mean bias lower than 0.02 in the shortwave and about 0.03 units in the PAR. The scatter distributions for high albedo values between POLDER and MODIS is however unbiased. The overall performance of GEOV1 with POLDER is 0.04/0.06 for shortwave/PAR domains, similar to that found between MODIS and POLDER. Note that, for high albedo values, the bias between GEOV1 and MODIS increases, whereas the bias between GEOV1 and POLDER decreases. Very similar scatter plots were obtained for the white-sky albedo (Figure 17). All performance statistics can be found in Annex B.

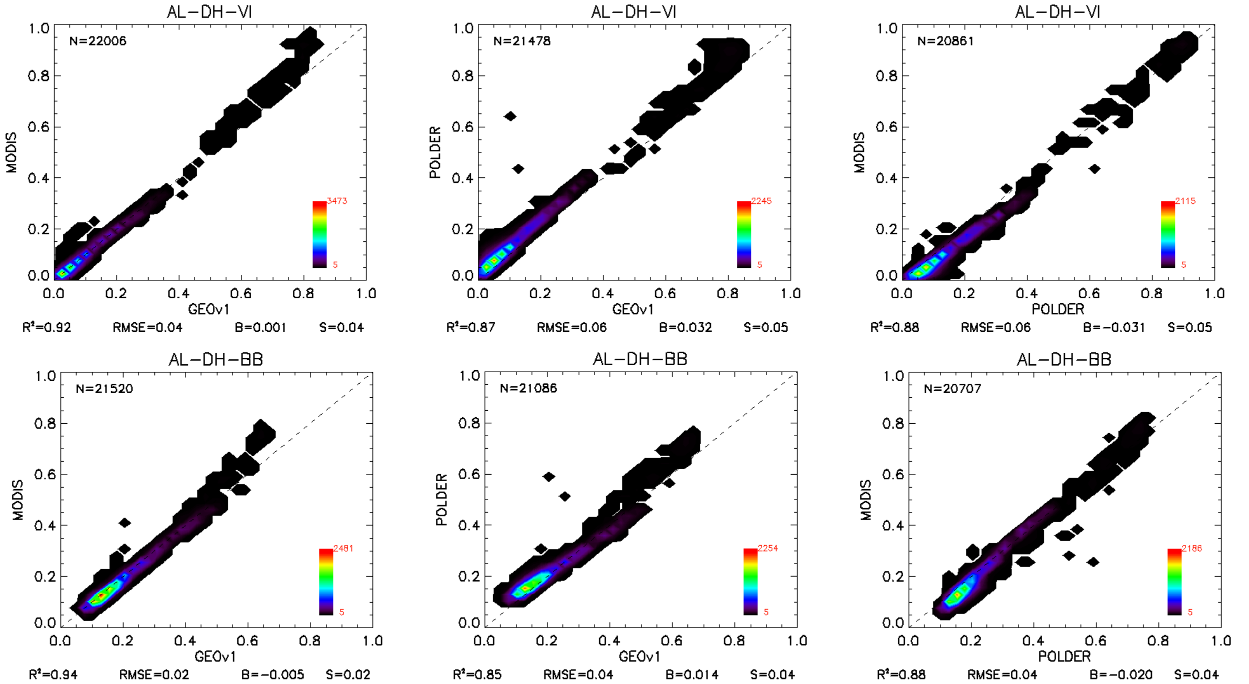


Figure 16: Directional-Hemispherical reflectance (AL-DH) product versus product scatter plots over all BELMANIP2 sites for the 2006-2007 period. Top: Visible domain (VI), Bottom: Total shortwave (BB). The terms B and S represent the mean and the standard deviation of the difference between the black-sky albedo products shown in the axes.

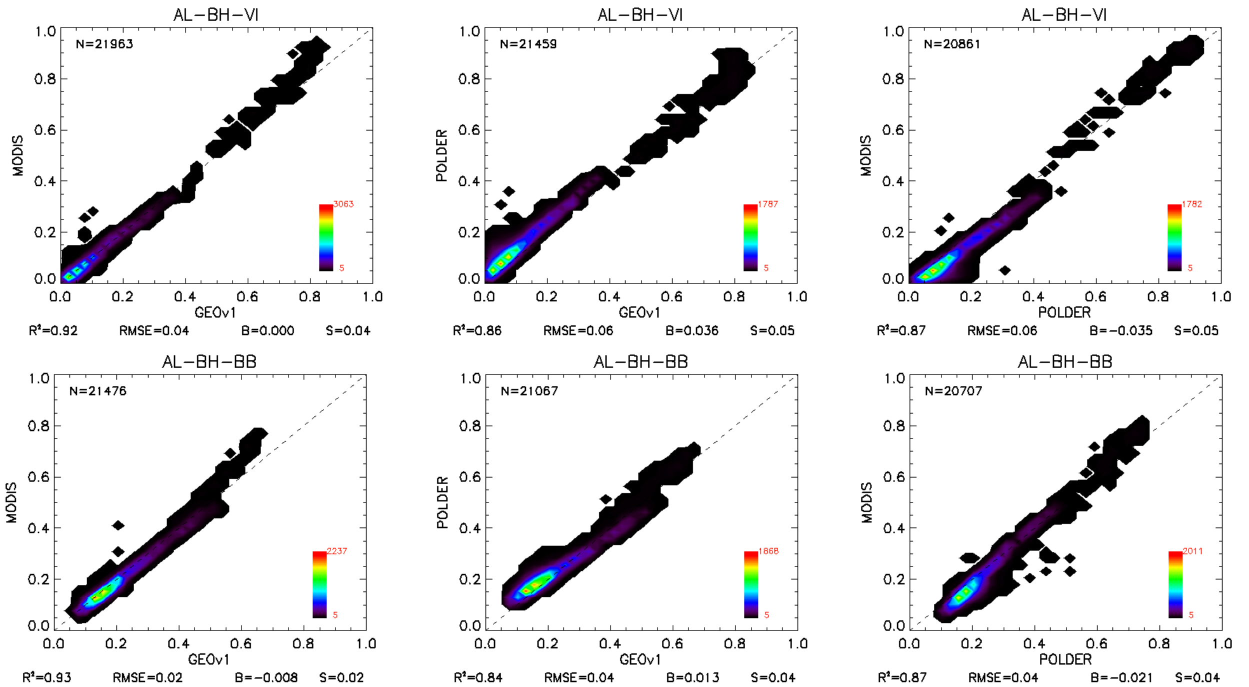


Figure 17: Bi-Hemispherical reflectance (AL-BH) product versus product scatter plots over all BELMANIP2 sites for the 2006-2007 period. Top: Visible domain (VI), Bottom: Total shortwave (BB). The terms B and S represent the mean and the standard deviation of the difference between the white-sky albedo products shown in the axes.

6.4.2 Temporal Variations of Metrics

Systematic differences between products show low temporal dynamic, with deviations typically around 0.01 regarding the mean value of the period (Figure 18). Note that the bias between GEOV1 and MODIS increases around December whilst the bias between GEOV1 and POLDER decrease in the same period, which is in agreement with the different behavior of the bias observed for snow albedo values in the above scatter plots. The RMSE shows a clear seasonality, with higher values during the wintertime in the north hemisphere. This may be explained partly due to the impact of the snow and the corresponding increase of albedo values and surface heterogeneity, but also due to higher BRDF errors in wintertime due to the larger anisotropy of surface's reflectance at larger illumination angles. It is noticeable the very low RMSE of about 0.01 found between GEOV1 and MODIS products from April to September.

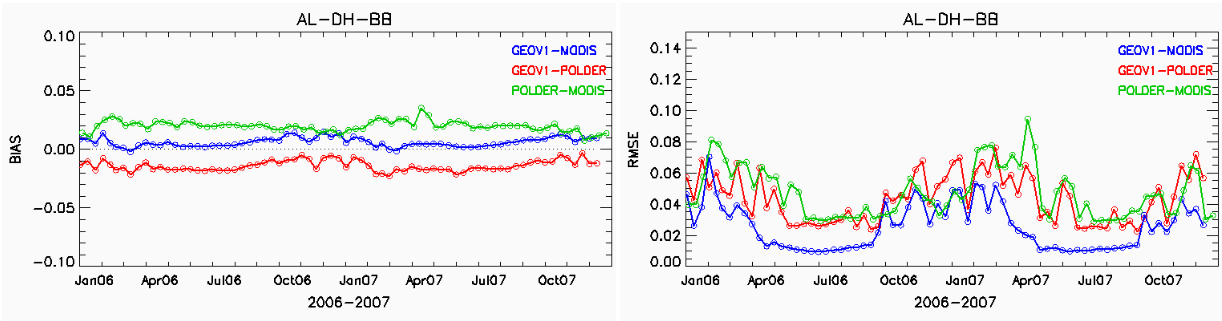


Figure 18: Temporal evolution of systematic (left) and overall (right) discrepancies between directional albedo products.

6.4.3 Distribution of Products per Biome Type

The distributions of black-sky albedo obtained from SPOT/VGT and MODIS products are very consistent for all the biome types in the shortwave (Figure 18) and the visible region (Figure 19). The exception is the Snow type, where MODIS displays the higher values in total shortwave and visible domain. Stroeve et al. (2005) concluded that MODIS albedos were largely accurate over regions of homogenous snow which in turns may indicate some uncertainty of SPOT/VGT retrievals over snow.

POLDER-3 albedo distributions are systematically shifted towards higher values except over Snow and over Bare Areas in the shortwave. Over Broadleaved Evergreen Forest the differences with POLDER-3 are very large. The better agreement is found for sparsely vegetation biomes (i.e. Shrubs, Herbaceous, Bare Areas). Note that for Bare areas the large discrepancies found over Sahara and Arabian deserts are not well captured for the BELMANIP-2 sites (Figure 18).

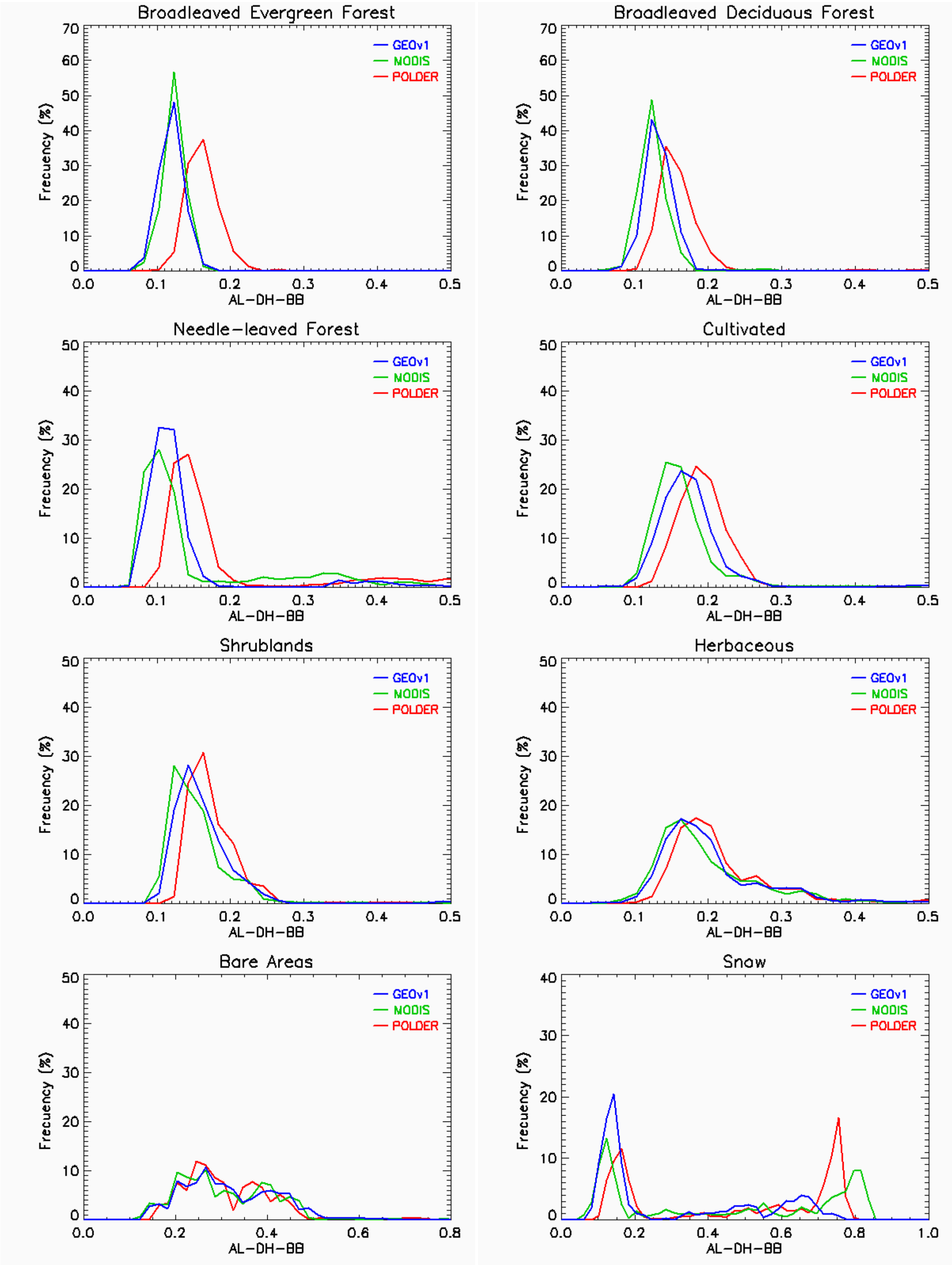


Figure 19: Distribution of shortwave broadband directional albedo (AL-DH-BB) values of each product for the BELMANIP-2 sites during the 2006-2007 period for each biome type.

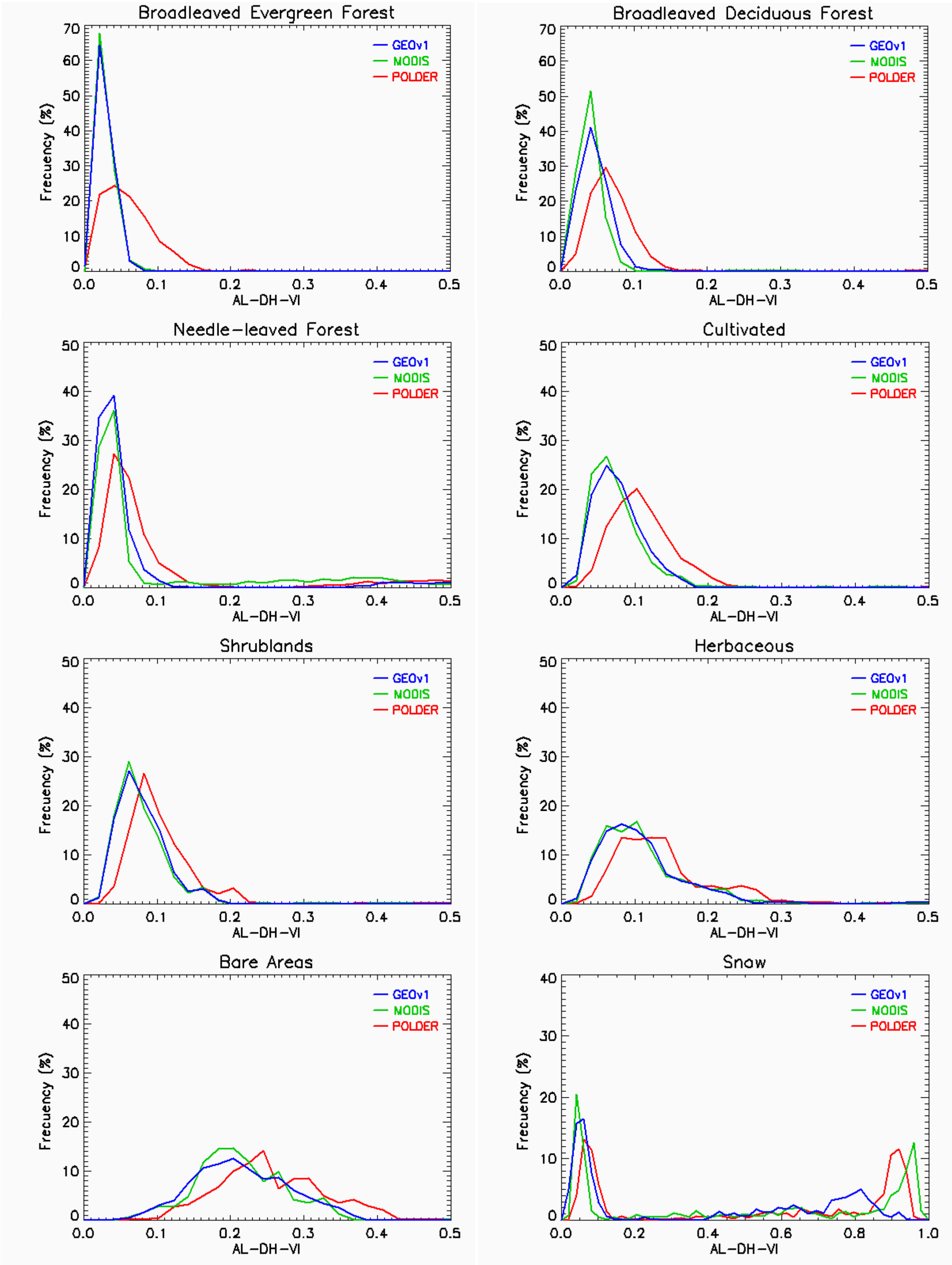


Figure 20: Distribution of VIS directional albedo (AL-DH-VI) values of each product for the BELMANIP-2 sites during the 2006-2007 period for each biome type.

6.4.4 Statistical Assessment per Biomes

In this section the performance metrics between shortwave black-sky albedo products are shown (Figure 21). Performance metrics for all broadband albedo quantities are provided in the Annex B.

Good correlations are generally found for non-forest types, whereas for the broadleaf forest biomes the correlations are much lower mainly as compared to POLDER products. Between GEOV1 and MODIS there is a very small mean bias, lower than 0.01, with slightly higher values of SPOT/VGT albedo product (except for Snow). Conversely, the mean bias is rather significant with POLDER products. The largest differences (up to 0.04) between GEOV1 and POLDER are for BEF, NLF and Snow. The lowest bias is for Bare Areas where GEOV1 provides higher albedo values and for Herbaceous. Note that MODIS overestimates albedo as compared to POLDER over large desertic regions such as Sahara, Arabia or Australia (Figure 10), although over the BELMANIP-2 distribution of desert samples the mean bias is around zero. The RMSE between GEOV1 and MODIS is below 0.03 except for Snow (0.06), whereas the RMSE between SPOT/VGT and POLDER is typically of 0.04 and up to 0.06 for NLF and Snow (even greater between MODIS and POLDER). Note that NLF should be largely affected by snow cover, and for larger anisotropy effects due to the larger sun zenith angles during wintertime. In relative terms, overall performance between SPOT/VGT and MODIS ranges typically between 10% and 15%, which is close to target accuracy level, and about 20% (threshold) for Snow. However, overall discrepancies with POLDER range between 10% and 20% only for non-forest types, whereas for forest types discrepancies are between 30% and up to 40% for NLF (which is beyond threshold level).

The causes of differences between POLDER and the other products cannot be inferred from these figures. The bias between POLDER and other remote sensing products is higher where larger BRDF effects are expected (eg., NLF) or low 'best-quality' observations due to higher cloudiness are available for BRDF inversion with MODIS or SPOT (eg., EBF). Hautecoeur and Roujean (2007) reported an overestimation of POLDER-3 albedo as compared to MODIS over Canadian boreal forest of about 0.06 units in agreement with our results. The higher consistency of SPOT/VGT and MODIS albedo products may be partly explained by more similarities in the directional sampling used for the BRDF model inversion. Conversely, POLDER-3 presents better directional capabilities for sampling the back-scattering directions where reflectance is much higher. Other factors such as calibration, atmospheric correction and cloud-screening or uncertainties in the narrow to broadband conversion could also contribute to the final discrepancies. To better understand these discrepancies, it would be also convenient to analyse discrepancies in the reflectance factor and BRDF signatures over well-known sites.

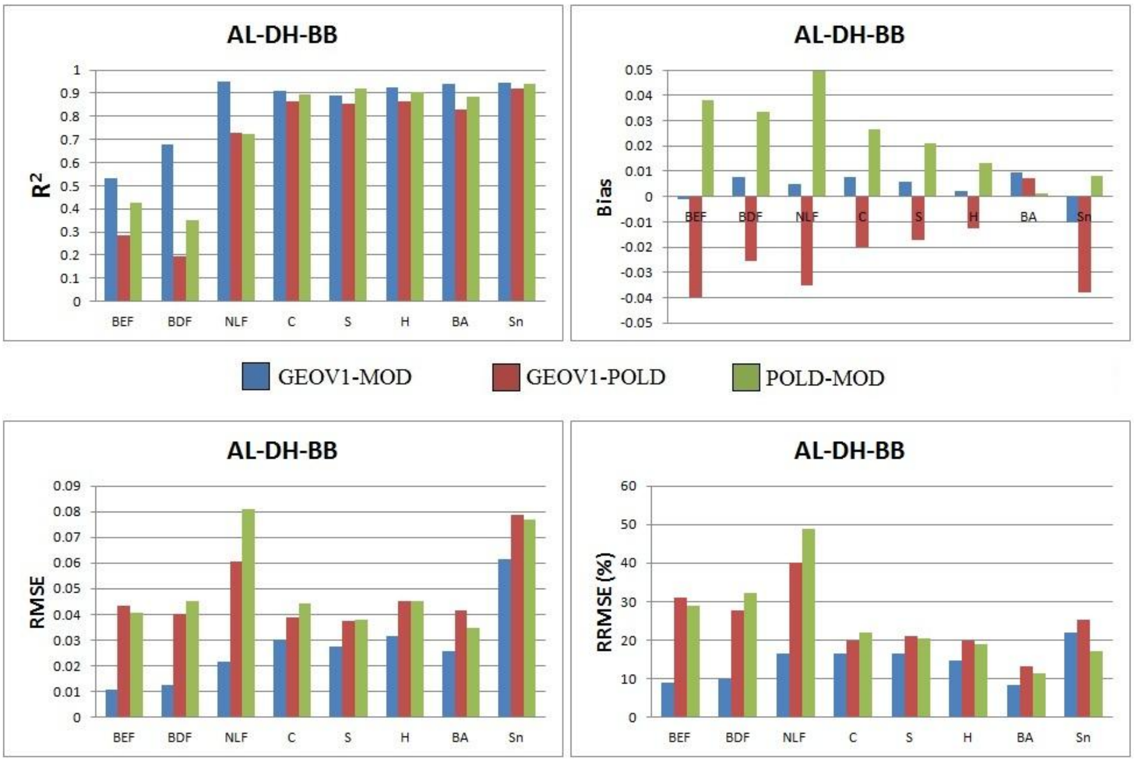


Figure 21: Statistical indicators (R^2, Bias, RMSE and relative RMSE) among different AL-DH-BB products per aggregated land cover types: Broadleaf Evergreen Forest (BEF), Broadleaf Deciduous Forest (BDF), Needle-leaf Forest (NLF), Shrublands (S), Herbaceous (H), Cultivated (C), Sparse and Bare Areas (BA), Snow (Sn).

For the visible and near-infrared albedo quantities all the metrics can be found in Annex B. For the visible a similar behaviour as a function of biomes was found. Note that discrepancies between GEOV1 and MODIS over snow are much larger in the visible domain (RMSE of up 0.01), and that POLDER-3 overestimates Bare Areas up to 0.04. In relative terms discrepancies are higher due to higher absorbance mainly over vegetated areas, and range between 20%-40%, except when comparing with POLDER-3 for forest sites where discrepancies ranges between 80-100% (twice than between GEOV1 and MODIS). For the NIR albedo, the peculiarity regarding the solar albedo is that MODIS is higher than GEOV1 in Broadleaf Forests and Bare Areas, whereas GEOV1 provides higher albedo values for Snow. The overall performance is around 0.02 (10%) except for Snow (0.025, 18%).

In summary:

Statistics confirm the optimal consistency between SPOT/VGT and MODIS solar albedos with very low systematic deviations (<0.01) coming mainly from high albedo values. RMSE is of about 0.03 which is about 13% in relative terms (close to target accuracy), and slightly higher in the VIS domain (0.04) and lower in the NIR domain (0.02). The comparison with POLDER shows higher bias, which is more important for the lower albedo values, and overall performance (RMSE) of *about 0.04 along the period but that exceed users requirements (i.e. absolute accuracy of 0.05) during large periods of the year.*

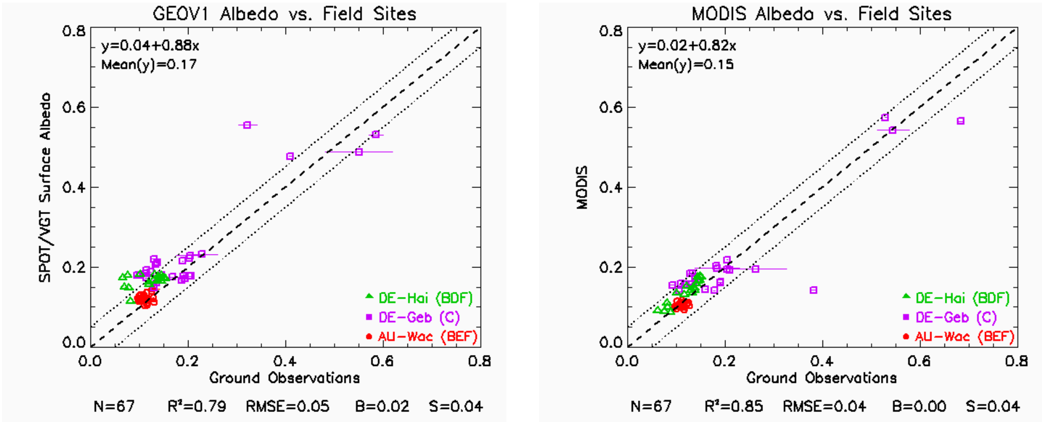
Per biomes, the performance of SPOT/VGT and MODIS products range between 0.01 (10% in relative terms) for broadleaved forests and 0.03 (15%) for Cropland and only for Snow/Ice sites the performance is lower (RMSE of 0.06 / 20%). As compared with MODIS, target accuracy is obtained for BEF, BDF and BA biomes, and only for snow a threshold level is found. As compared with POLDER, however, the largest discrepancies are found over forest, mainly the NLF sites with an RMSE up to 0.06 (40%) similar to that found in Snow/Ice pixels. For the broadleaf forest the RMSE is around 0.04 similar to other biomes, but higher in relative terms 30%. Cropland, Herbaceous and Shrublands show discrepancies of about 20% (threshold level) and only Bare Areas are within the 10% target accuracy level.

6.5 DIRECT VALIDATION

To investigate the accuracy of the satellite albedo products, scatter plots versus field measurements were produced for the year 2006 over three FLUXNET sites of different vegetation type (Figure 22). This exercise was performed at the lower spatial resolution of POLDER (6 km) for inter-comparison purposes, but considering only sites where the albedo at 6-km resolution was almost equivalent to the value over 1-km. GEOV1 and MODIS showed a RMSE of 0.05 and 0.04 respectively (i.e., target accuracy), whereas POLDER showed the lower correlation and a RMSE of 0.07 units. MODIS was the most accurate over these sites (no bias), and POLDER displayed the largest overestimation of field values. Note the good agreement of MODIS and GEOV1 over broadleaf evergreen forest site (AU-Wac), a biome where POLDER provides larger albedos. A larger sample of field sites should be considered to confirm the better accuracy of MODIS or GEOV1 as compared to POLDER.

The accuracy of SPOT/VGT surface albedo at 1-km resolution was also investigated using eight sites and two years (2003-2004) period (Figure 23). Considering the whole period an RMSE of 0.06 and a bias of -0.015 were obtained, with most of the points falling within the ±0.05 interval. The mismatch between the satellite and ground observations are the major factor contributing to the discrepancy between the SPOT/VGT albedo and the field measurements, which is more important when the sub-pixel heterogeneity increases for instance due to mixed snow/vegetation patterns. On the other hand, the parametric BRDF model is not well suited for accurately reproduce the anisotropy of snow/vegetation surface's reflectance. Consequently, the accuracy improves considerably if only snow-free observations are considered. In such case, an RMSE of 0.03 with no systematic deviations was obtained.

This exercises points to a target accuracy of SPOT/VGT albedo retrievals, but further research is needed to account for a larger number of validation sites.



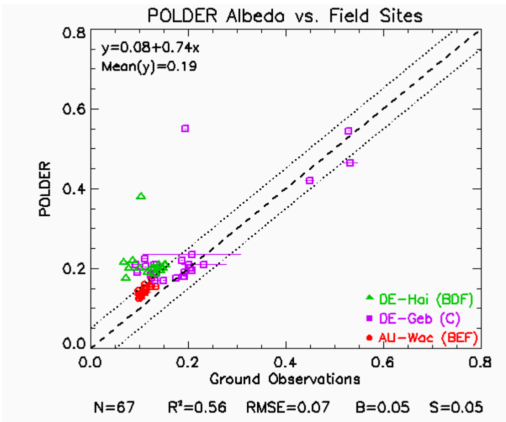


Figure 22: Scatter plot of surface albedo (at Local Solar Noon) from satellite products versus field measurements for four sites (between brackets the biome acronym) for the year 2006. The horizontal line represents the standard deviation of the field measurement during the compositing period. The dashed lines correspond to the ±0.05 units.

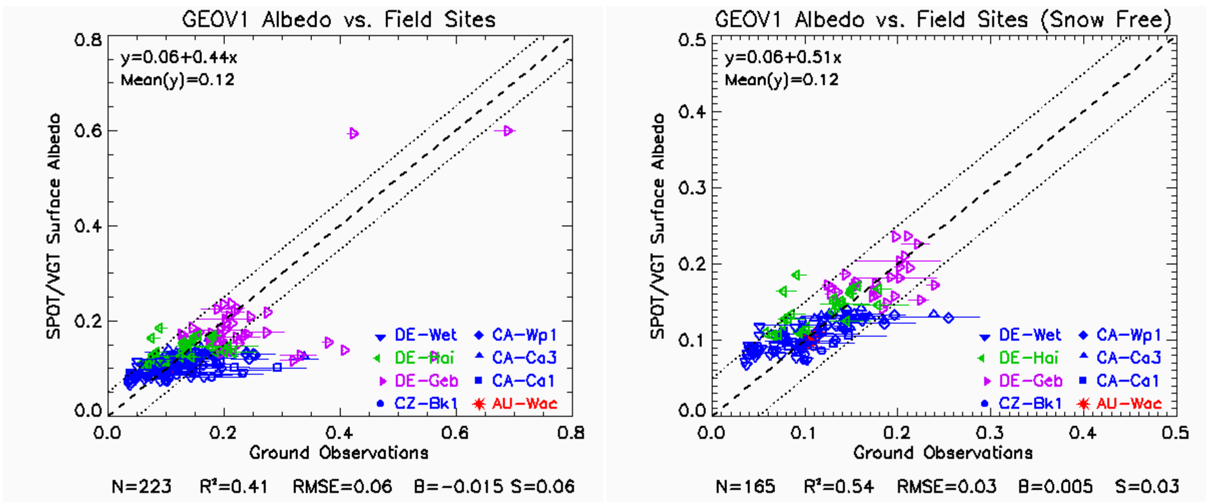


Figure 23: Scatter plot of GEOV1 surface albedo (at Local Solar Noon) from satellite products versus field measurements for eight FLUXNET sites (Blue for NLF, Green for BDF, Magenta for Cropland, Red for BEF) for the 2003-2004 period. The horizontal line represents the standard deviation of the field measurement during the compositing period. The dashed lines correspond to the ±0.05 units.

In summary:

Over a small number of sites considered the SPOT/VGT surface albedo reaches the required target accuracy of 0.05. The overall performance is better over snow-free pixels (0.03) and no systematic deviations were observed. This analysis however is not representative of the global conditions and should be complemented with additional sites in the future.

6.6 REGIONAL ASSESSMENT

In this section a special focus on comparison of albedo products covering Europe and part of North of Africa was considered. MSG albedo products were included. All the performance metrics for the different albedo quantities are provided in Annex C.

Figure 24 shows a map of each shortwave black-sky albedo product under study around 15th of May, 2007. Consistent spatial distribution of retrievals is observed, showing POLDER higher values over large part of central Europe.

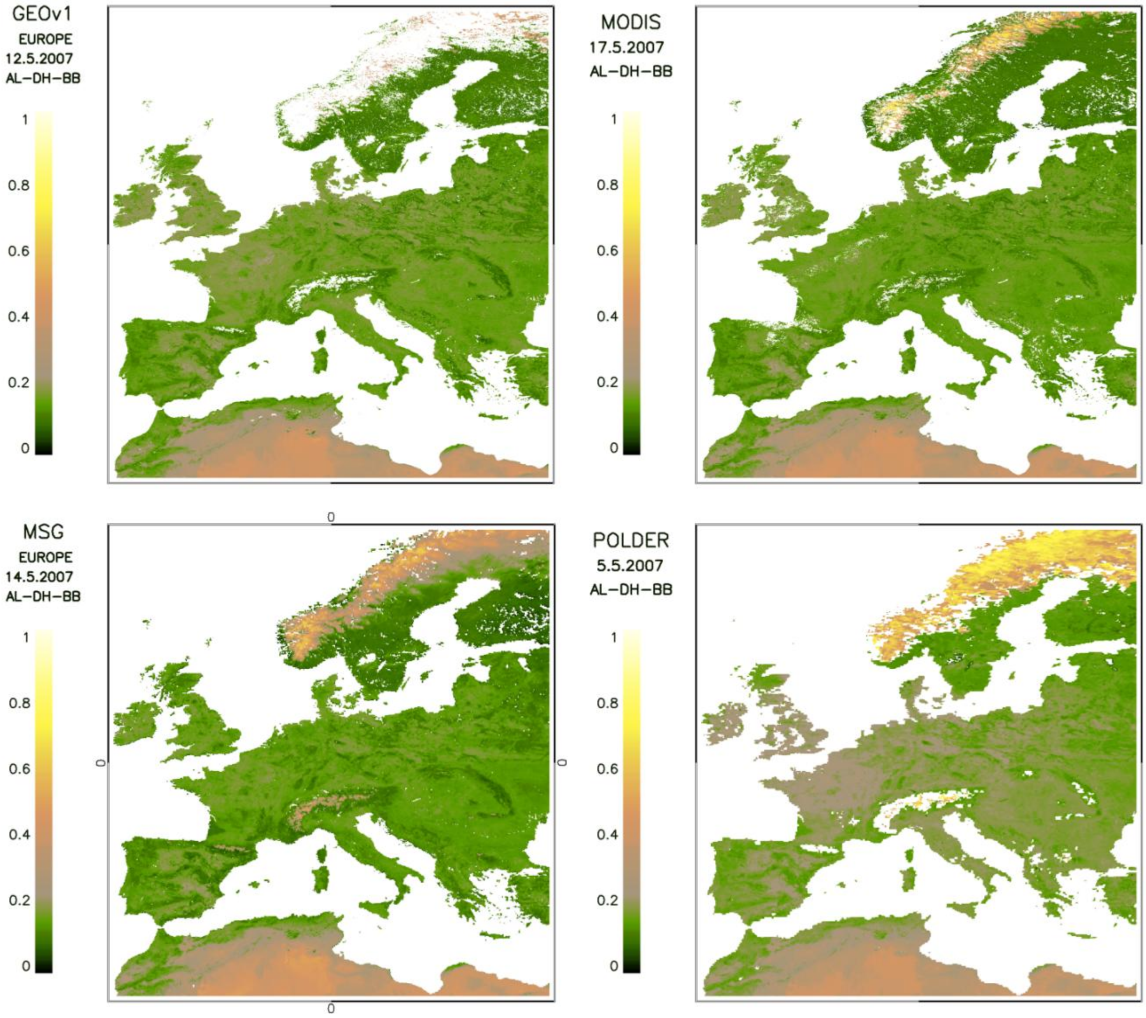


Figure 24: Shortwave directional albedo products over Europe around mid May, 2007.

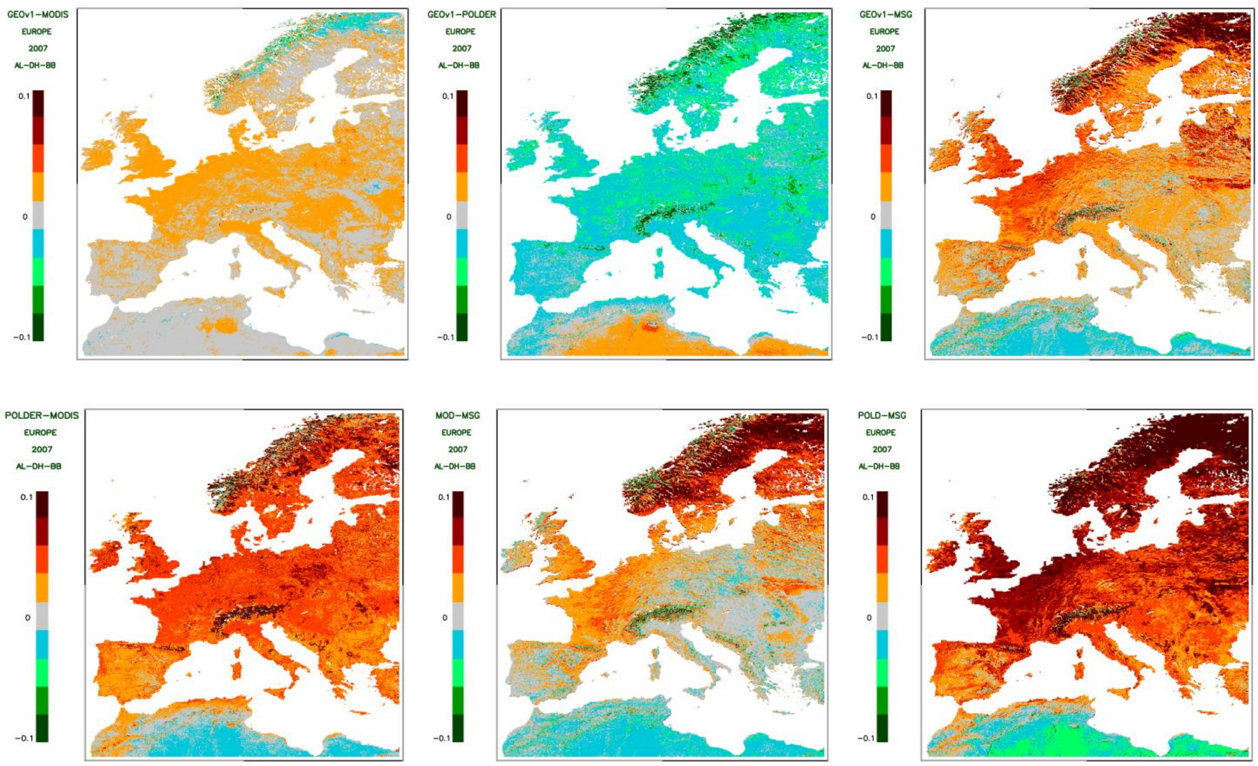


Figure 25: Maps of mean differences between shortwave difference albedo products during the year 2007 over the European region.

The spatial consistency between GEOV1 and MODIS is very good over South of Europe and North Africa, showing very low mean bias (slight overestimation of GEOV1) during the 2007 year (Figure 25). POLDER albedo displays higher values than GEOV1 and MODIS except over the Sahara desert, with larger discrepancies over northern latitudes. Conversely, the opposite trend was found when comparing GEOV1 with the Land-SAF MSG albedo. Higher albedo values are provided by SPOT/VGT products with larger bias (up to 0.1) over northern latitudes, whereas the MSG albedo is slightly higher over desert. Note that the albedo retrieval based on MSG/SEVIRI is more inaccurate over high latitudes (Geiger et al., 2008). This is partly due to SEVIRI observes high latitudes at large view zenith angle and so the BRDF retrieval uncertainties are larger (kernels tend to diverge at large angles). The lower consistency was found between POLDER-3 and MSG products. POLDER-3 largely overestimates MSG retrievals over Europe, showing mean bias higher than +0.05 over large areas, and going up to +0.1 over Scandinavia where MSG is more inaccurate. Conversely, MSG albedo is higher over Sahara desert in agreement with findings reported in Hautecoeur and Roujean (2007).

Large uncertainties of the BRDF/albedo in Europe appear mainly in wintertime as a combination of multiple effects. The large illumination angles that increase the anisotropy of reflectance, (e.g. by increasing the mutual shadowing by tree crowns), the snow cover which increase the subpixel heterogeneity and the specular reflection, higher cloudiness and so lower number of looks for the

BRDF retrieval. These uncertainties over northern latitudes are larger for geostationary sensors due to the large viewing angles. In addition, some of the discrepancies found with MSG may be attributed to the fact that a static model for aerosols is used in the atmospheric correction, whereas aerosol estimates are used in the MODIS or POLDER processing chains..

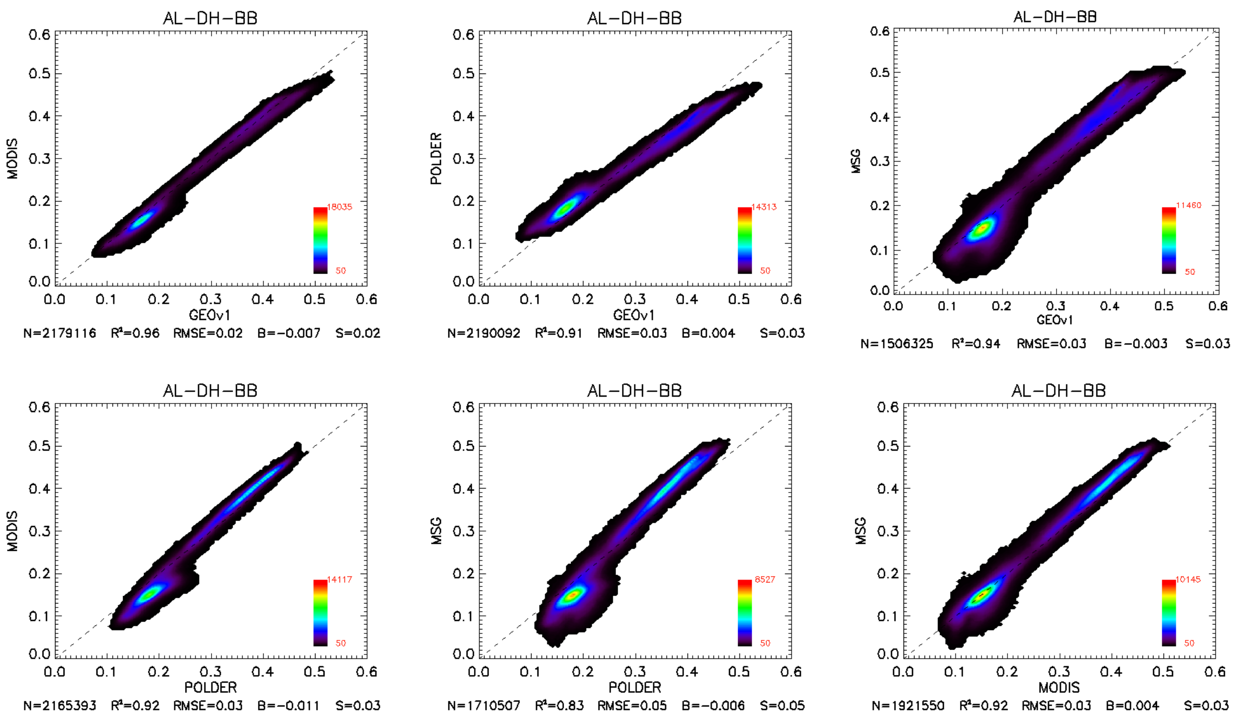


Figure 26: Broadband Directional-Hemispherical reflectance (AL-DH-BB) product versus product scatter plots over homogeneous land-cover type sites for the 2007 period. The terms B and S represent the mean and the standard deviation of the difference between the black-sky albedo products shown in the axes.

Figure 26 shows the scatter plots between pair of solar black-sky albedo products. GEOV1 albedo estimates show optimal correlation with MODIS retrievals (0.96), a slight overestimation mainly for albedo values below 0.3, and the best overall performance of about 0.02 units. The comparison with MSG estimates shows a performance of about 0.03. Note that GEOV1 displays higher albedos for low albedo values (vegetated areas) whereas MSG provides higher albedos for high values (sparse and bare areas). The opposite trend is found between GEOV1 (or MODIS) and POLDER-3: POLDER shows higher estimates for low albedo values and lower values for high albedos. Consequently, the discrepancies between POLDER and MSG are more important (RMSE up to 0.05 and the lowest correlation of 0.83). Finally, it should be noted the very good agreement found between MODIS and MSG for shortwave albedo values lower than 0.03.

The analysis per biomes shows larger bias and RMSE for Forest and Croplands (Figure 27). The larger bias and RMSE error found over NLF should be mainly explained by the uncertainty of the retrieved BRDF. NLF is a biome with a complex canopy architecture which is under snow conditions during several months. Furthermore, NLF is largely distributed over northern latitudes which are observed under larger illumination (and observation for SEVIRI) angles. Better performances were found over Herbaceous and Bare areas where a lower anisotropy due to 3D-canopy structure and large illumination angle is expected. The better agreement was found always between GEOV1 and MODIS, with RMSE between 0.01 and 0.02 for all biomes except for NLF where RMSE is slightly higher (0.03). The consistency between GEOV1 and MODIS is notably better than between other albedo products. The worst overall performances for all biomes were found between POLDER and MSG products with a RMSE values ranging from 0.04 to 0.09.

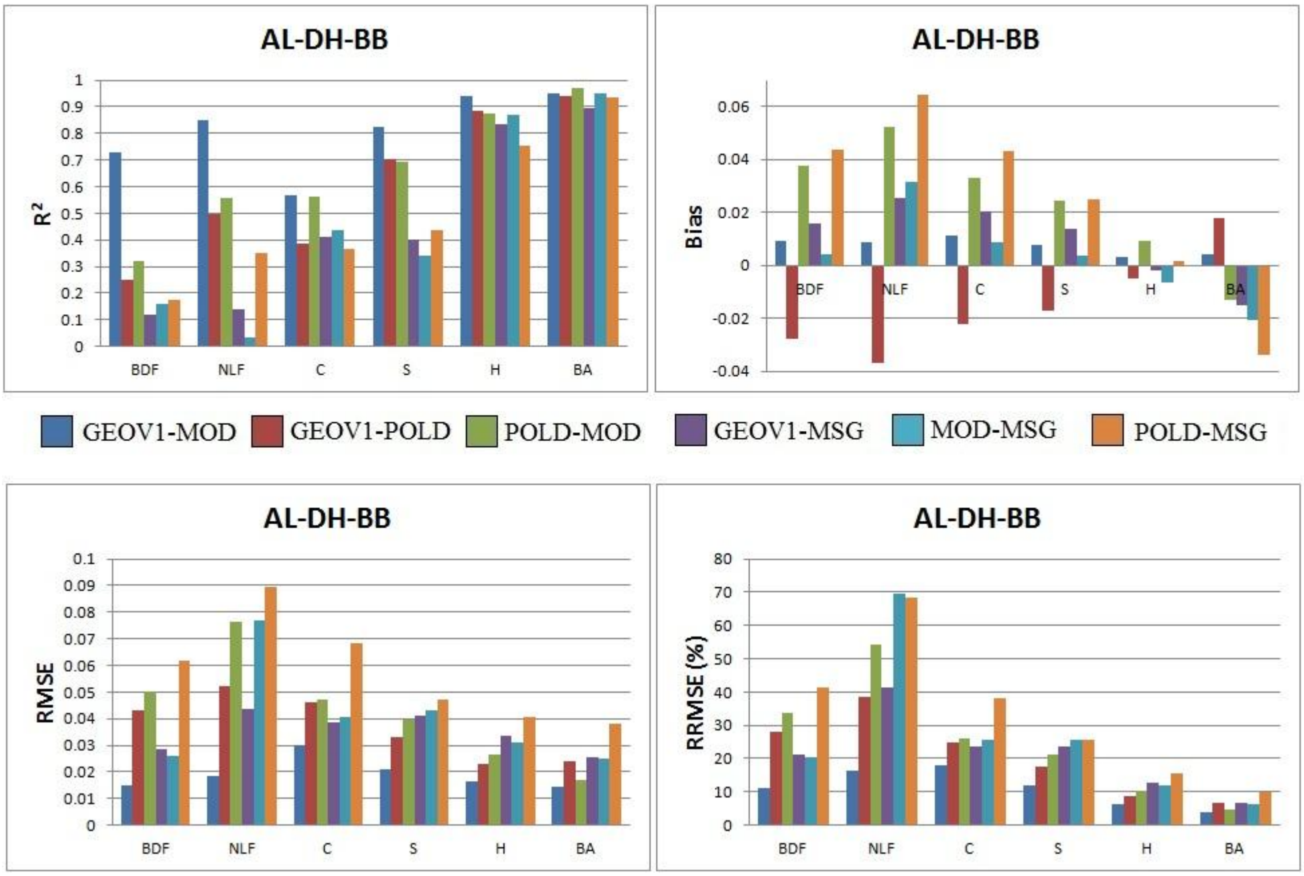


Figure 27: Statistical indicators (R^2, Bias, RMSE and relative RMSE) among different AL-DH-BB products over the European region per aggregated land cover types: Broadleaf Deciduous Forest (BDF), Needle-leaf Forest (NLF), Cultivated (C), Shrublands (S), Herbaceous (H), Cultivated (C), and Bare Areas (BA).

In summary:

The special focus on the European window confirms most of the results of the global analysis. GEOV1 and MODIS perform admirably for all the biomes with RMSE ranging between 0.01 and 0.03. The lowest performances were found between MSG and POLDER albedo products with RMSE ranging between 0.04 and 0.09. The Needle-leaf forest type shows the largest *discrepancies between the remote sensing products, which may be explained due to the complex BRDF effects mainly under snow conditions and large illumination angles (northern latitudes).*

7 CONCLUSIONS

In this study, a scientific validation of the Global Land SPOT/VGT GEOV1 Albedo product was performed. The methodology used was adapted from the guidelines proposed by the CEOS LPV group for validation of remote sensing vegetation products. First, an inter-comparison with existing global products (MODIS C5, POLDER-3/PARASOL) was performed at 6-km spatial resolution and 10-days frequency to analyse the spatial and temporal consistency of the SPOT/VGT products. The BELMANIP-2 global network of sites was used to perform the statistical analysis. The accuracy was quantified by direct comparison with FLUXNET ground measurements over a few numbers of homogeneous sites. Moreover, a special focus over Europe, including Land-SAF MSG Albedo product, was carried out. Several criteria of performance including spatio-temporal continuity, spatial distribution, realism and smoothness of temporal profiles and the performance via direct and indirect validation were evaluated. The main conclusions are summarized below:

Spatio-temporal continuity

For high latitudes and equatorial regions the lack of spatial continuity is very high, especially during winter in the north hemisphere (and even larger when QF information is considered). This is one of the main drawbacks of the GEOV1 SPOT/VGT Albedo and the other polar orbiting satellite products, in contrast to products derived from geostationary sensors such as the Land-SAF MSG albedo products with no gaps. The GEOV1 albedo products based on combination of geostationary satellite data can contribute to overcome this limitation, providing better spatial continuity over these regions, although at a lower spatial resolution.

Spatial Consistency

SPOT/VGT and MODIS products present very similar global spatial distributions of broadband albedo quantities, large areas of America, Africa, Asia and Oceania displays mean differences during the period within ±0.01 for the total shortwave. SPOT/VGT albedo displays slightly higher values mainly over Europe, North Africa, South-East Asia, whereas MODIS albedo is higher over Boreal and Polar areas (bias up to 0.1) where the impact of snow/ice is more important. However, the spatial consistency of both SPOT/VGT and MODIS products with POLDER-3 is much lower, and significant differences were observed. Similar to MODIS (except for the Polar regions), the SPOT/VGT Albedo quantities (BB and VIS) are systematically lower than that of POLDER-3, with mean differences around -0.05 over equatorial belt and over high latitudes in the northern hemisphere. The systematic discrepancies are still larger (up to 0.1) over some regions (Greenland, Tibetan Plateau, Siberia). However, for the shortwave, SPOT/VGT albedo is higher over desert. The focus over Europe shows larger inconsistencies over northern latitudes, mainly when comparing with MSG albedo. The larger discrepancies were found between POLDER-3 and MSG products.

Temporal consistency

Temporal variations of SPOT/VGT Albedo product are very consistent with both ground observations and other satellite products. The product responds generally well to strong albedo changes due to persistent snow events and to smooth seasonal variations over the different vegetation biomes. However, as compared to other products, SPOT/VGT Albedo fails to reproduce sporadic (i.e., few dates) snow events, and tends to exhibit larger fraction of missing values over snow. The main discrepancy was found over desert sites: the seasonal variation of the SPOT/VGT directional albedo was found higher than other products, which has been attributed to the anomaly detected in the VGT-P data related to the standardization of solar illumination. No seasonal variation was found with MSG over desert sites.

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

Uncertainties

The comparison with field data for FLUXNET homogeneous sites where diffuse fraction was measured shows a RMSE of about 0.05 (target accuracy) and albedo underestimation for mixed snow/vegetation pixels. The performance for snow-free values is of 0.03 with a slight positive bias of GEOV1 albedo of only 0.005. This exercise however is not well representative of the different biomes, and should be improved in the future estimating the fraction of diffuse fraction from aerosols.

Table 8: Performance of SPOT/VGT ALBEDO products against reference satellite products over BELMANIP-2 sites for the 2006-2007period. Positive bias indicates overestimation of reference values.

	AL-DH-BB			AL-DH-VI			AL-DH-NI
	MODIS	POLDER3	MOD-POL	MODIS	POLDER3	MOD-POL	MODIS
Correlation	0.94	0.86	0.88	0,92	0,88	0,88	0,96
Bias	0.006	-0.014	0.02	-0.0015	-0.03	0.03	-0.0008
RMSE	0.03	0.04	0.05	0.04	0.06	0.06	0.02
	AL-BH-BB			AL-BH-VI			AL-BH-NI
	MODIS	POLDER3	MOD-POL	MODIS	POLDER3	MOD-POL	MODIS
Correlation	0.96	0.84	0.87	0.92	0.86	0.87	0.95
Bias	0.008	-0.014	0.02	-0.0005	-0.04	0.04	0.0001
RMSE	0.03	0.04	0.05	0.04	0.07	0.07	0.02

Table 9: Performance of SPOT/VGT ALBEDO broadband products against reference satellite products over BELMANIP-2 sites for the 2006-2007 period for snow-free observations (AL<0.5). Positive bias indicates overestimation of reference values

Snow-Free (AL<0.5)	AL-DH-BB		
	MODIS	**POLDER3**	**MOD-POL**
Correlation	0.95	0.91	0.89
Bias	0.008	-0.012	0.02
RMSE	0.019	0.03	0.04
	AL-BH-BB		
	MODIS	**POLDER3**	**MOD-POL**
Correlation	0.94	0.88	0.88
Bias	0.009	-0.012	0.02
RMSE	0.02	0.03	0.04

The overall discrepancies between GEOV1 and the reference global albedo products were quantified over BELMANIP-2 sites representing global biomes and climatic conditions for the 2006-2007 period (Table 8). The SPOT/VGT albedo performs remarkably well with MODIS, with a mean bias and RMSE for the shortwave black-sky albedo lower than 0.006 and 0.03 (13% in relative terms) respectively. For the visible and NIR directional albedo products the overall performance is about 0.04 (30%) and 0.02 (8%), respectively, with no bias. Discrepancies are larger when comparing with POLDER-3 products: for the shortwave black-sky albedo a mean bias of -0.014 and RMSE of 0.04 (20%), whilst for the visible black-sky albedo a larger systematic underestimation of 0.03 and RMSE of about 0.06 (40%) was found. The discrepancies between SPOT/VGT and POLDER are slightly lower that when comparing MODIS and POLDER albedo quantities in the solar domain. Very similar uncertainties were found when comparing the white sky albedo products. The performance metrics are better if only snow-free pixels are considered (Table 9). This overall performance figures are however land-cover dependent and large uncertainties are found over some biomes (or regions) or specific periods (e.g. wintertime).

As refers to the period, the uncertainties are lower from April to October and increases notably from November to March, which may be partly explained by the effect of snow cover, large BRDF errors due to larger illumination angles or higher cloudiness over the northern hemisphere during the winter months.

<u>Land cover types</u>

SPOT/VGT and MODIS shortwave albedo quantities are very consistent for all biomes, with mean bias within ±0.01. SPOT/VGT shortwave albedo is slightly higher than MODIS except for Snow/Ice. Best performance (better than 10%) was found for Broadleaf forest and Bare Areas, and similar performances of about 15% for the other types. For Snow/Ice the RMSE is 0.06 (20%). However, as compared with POLDER-3 we found a different behaviour, and the forest biomes present higher discrepancies than non-forest types, similar to that found for Snow. The lowest performance is for needle-leaf forest (RMSE of about 0.06, 40%), and of about 0.04 (30%) for the broadleaf forest biomes, mainly due to systematic underestimation as compared with POLDER-3, which is in relative terms greater than for snow (25%). The larger discrepancies found for the needle-leaf forest may be partly explained by large uncertainties in the BRDF characterization due to the different directional sampling and BRDF model used, which should be more important over needle-leaf forest for a number of reasons (e.g., complex architecture, snow, illumination geometry,..). However, large systematic discrepancies found for other forest biomes may indicate other reasons such us cloud residuals or uncertainties in the narrow to broadband conversion. The comparison with MSG over Europe shows larger uncertainties for NLF (0.04, 40%) and better performances for bare areas (0.02, 5%) and herbaceous types (0.03, 10%).

Concluding remarks

Our validation analysis demonstrates that the SPOT/VGT GEOV1 albedo products are comparable to that of MODIS MCD43B3 (best quality) C5 albedo products, except for Snow/Ice pixels. Assuming that the MODIS albedo product is a good validated reference, we conclude that SPOT/VGT Albedo product is of good quality over the globe, presenting some limitation under snow conditions. Temporal profiles are typically consistent with satellite and ground variations and generally reproduce well variations due to strong snow cover changes, but however fails to detect sporadic snow falling events. The anomaly detected in the VEGETATION processing chain related the standardization of the solar illumination angles seems to be responsible of the larger seasonality of albedo observed over calibration sites. This anomaly however does not introduce apparently effects over vegetated sites, where seasonal variations in the vegetation canopy dominate the observed changes in albedo along the year. As compared with MODIS very small biases was observed for all biomes (except for snow) with an overall performance for the shortwave albedo quantities (DH, BH) of about 0.03 (13%) for all BELMANIP-2 pixel, and of about 0.02 (10%) for snow-free pixels. Larger discrepancies were found comparing with POLDER-3 and MSG products, but lower than when comparing these satellite products between them. The higher uncertainties are expected over northern latitudes and Needle-leaf forest mainly during boreal winter, but also over broadleaf forests and desert larger discrepancies were found with POLDER.

This analysis does not allow identifying the reasons of differences observed between SPOT/VGT and MODIS products on one hand, and POLDER-3 products on the other hand. They can come from the differences in atmospheric correction, the BRDF model, angular sampling, conversion coefficients from narrow to broadband, or a combination of factors. Further analysis should be done to better understand the observed discrepancies. As a conclusion, no elements say that POLDER-3 albedo is better than SPOT/VGT or MODIS albedo, even though the directional capabilities of POLDER instrument are obviously much better.

SPOT/VGT albedo products reach good performance for most of the criteria examined (Table 10). However, the error field seems not realistic and the Quality Flag may discard reliable snow retrievals. The results presented in this report are highly significant and hence we conclude that the Global Land GEOV1 Albedo products have reached the needed scientific quality to be released to the user community.

Table 10: Summary of Product Evaluation. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

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

According with the CEOS/LPV validation procedure the GEOV1 albedo are validated stage 2 "product accuracy assessed over widely distributed set of location and time periods via several ground truth and validation efforts. Spatial and temporal consistency of the product and with similar products has been evaluated over globally representative locations and time periods.

8 OUTCOME OF QUALITY MONITORING

The Quality Monitoring is performed on the Global Land products every 6 months. The objective is to verify that the recent operational products keep the same level of quality during the period under study than the products of the fully validated reference period. The procedure, criteria and metrics are the same than those applied in this document.

For SPOT/VGT GEOV1 albedo products, 3 quality monitoring exercises were performed between 1st January 2013 and mid-2014 since the production of SPOT/VGT GEOV1 Albedo products stopped in May 2014, at the end of the SPOT/VEGETATION mission.

Table 11: Summary of evaluation of 2013-2014 SPOT/VGT GEOV1 Albedo product. The plus (minus) symbol means that the product has a good (poor) performance according to this criterion.

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

Table 11 summarizes the main outcomes of these quality monitoring studies. Compared to the analysis presented in this document, the accuracy assessment by comparison of satellite-derived products with ground measurements was improved using in-situ data from several networks (SURFRAD, ARM BSRN and AMERIFLUX). The evaluation demonstrates that the recent SPOT/VGT Albedo products keep the same level of quality that the validated products (2006 and 2007) for all the criteria examined (**Erreur ! Source du renvoi introuvable.**11).

As 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 12). The last column states in how far these requirements are met by SPOT/VGT surface albedo products.

Table 12: Compliance matrix of GCOS, WMO and geoland2 requirements for GEOV1 Surface albedo products.

Requirement	Source	Objective	Match
Horizontal Resolution	GCOS	1 km	Yes
	WMO	Goal (1km)	Yes
Temporal Resolution	GCOS	Daily to weekly	No, SPOT/VGT Temporal Resolution = 10 days
Observing Cycle	WMO	Goal (24h) Breakthrough (3d) Threshold (90d)	Threshold, SPOT/VGT observing cycle: 30 days
Timeliness	WMO	Goal (30d) Breakthrough (45d) Threshold (90d)	Goal
Accuracy	GCOS	Max(5%; 0.0025)	No, RMSE=20% snow-free pixels
	BioPar	Optimal (5%) Target (AL > 0.15: 10% AL < 0.15: 0.03) Threshold (20 %)	Target, over snow-free pixels. RMSE=0.03 for AL<0.15
	WMO	Goal (5%) Breakthrough (7%) Threshold (10%)	No, RMSE=20% snow-free pixels
Stability	GCOS	Max(1%; 0.0001)	Yes, in terms of Bias <1% over desert calibration sites. In terms of RMSE is 2%

9 RECOMMENDATIONS

Here are some recommendations resulting from the quality analysis:

- The most important error is the incorrect implementation of the Sun-Earth distance in the input SPOT/VGT data. This will be corrected during the reprocessing of the SPOT/VGT archive. Once done, the Global Land surface albedo time series shall be re-generated, and the quality assessment analysis redone.
- Another important limitation comes from the lack of completeness of the product. It is thus recommended to implement a strategy for gap filling based on climatology of albedo products, or to evolve the algorithm toward a multi-sensor approach to improve the spatial coverage of the product.
- Some limitation in the snow areas have been detected that can be associated to the normalization of the BRDF products and rejection of outliers. It would desirable to overcome this situation, and do not reject snow observations during the BRDF composition.
- Finally, the Quality Flag can be also improved, in order to no discard valid snow observations as invalid input.

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SPOT/VGT GEOV1 Albedo products used in this analysis are property of CNES under copyright FP7/geoland2 (Reference No 218795). They are generated from the SPOT VEGETATION data under copyright CNES and distribution by VITO.

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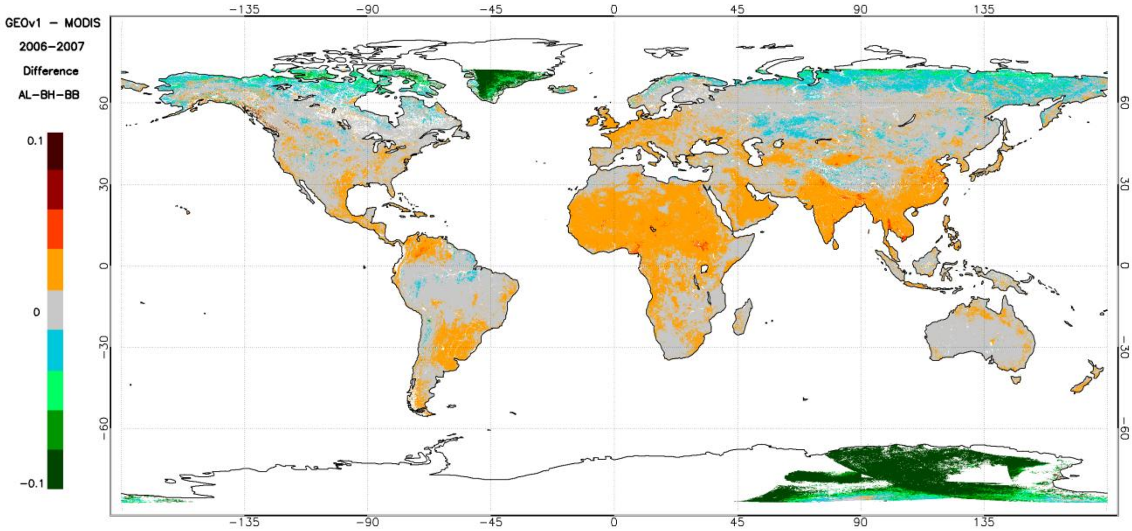
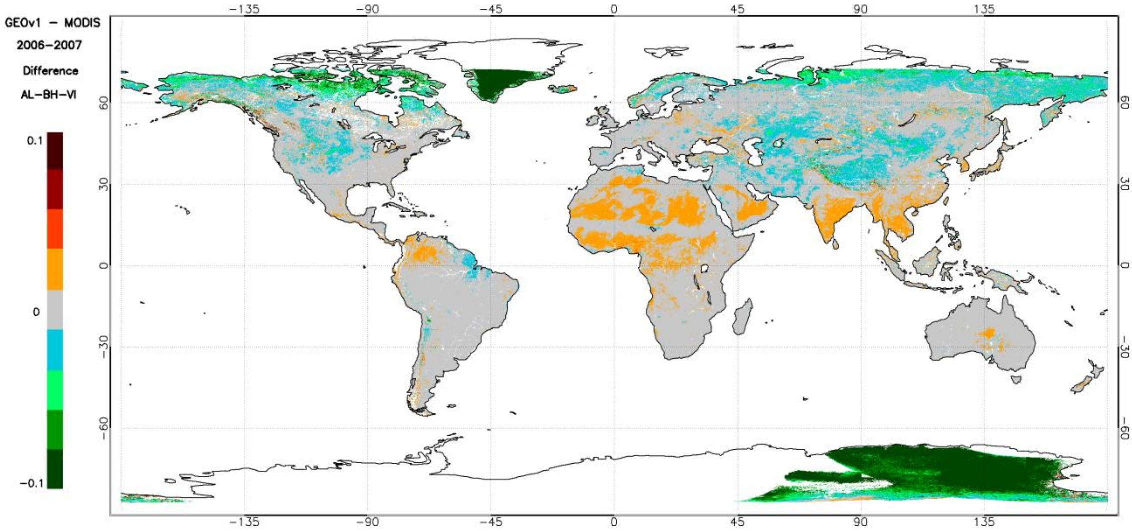
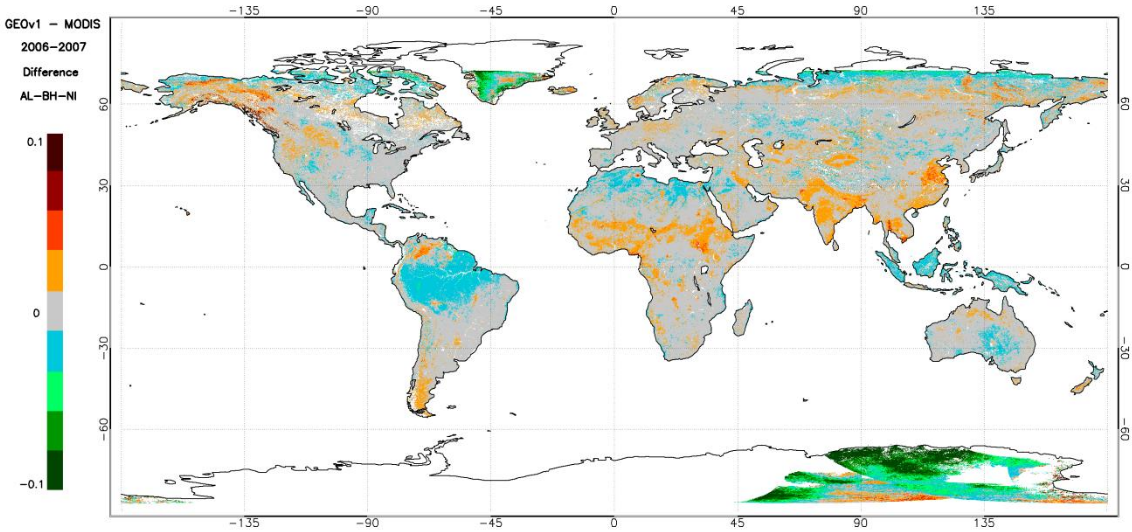
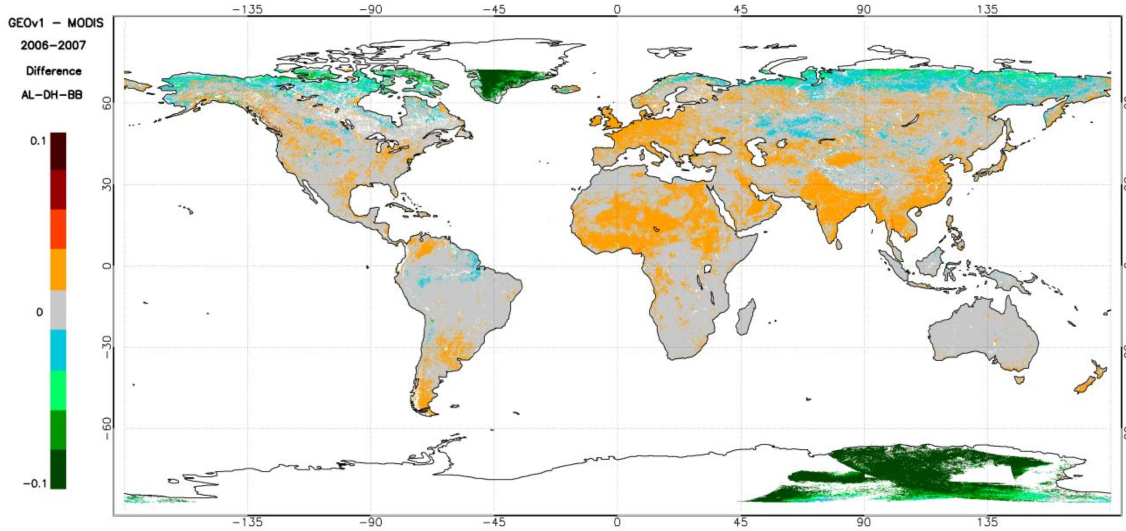
ANNEX A: MAPS OF MEAN DIFFERENCE BETWEEN ALBEDO PRODUCTS FOR THE 2006-2007 PERIOD

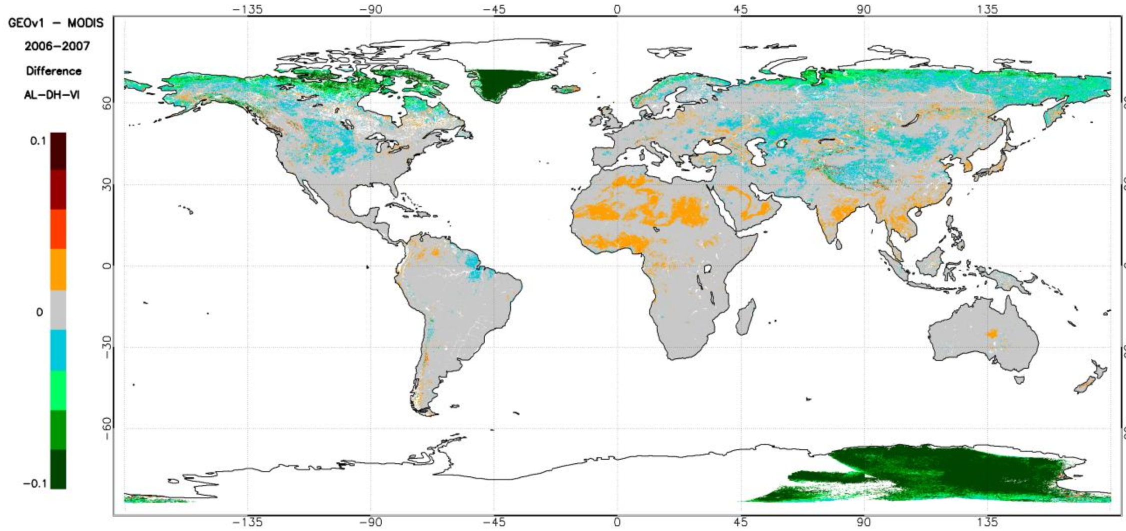
GEOV1 vs MODIS

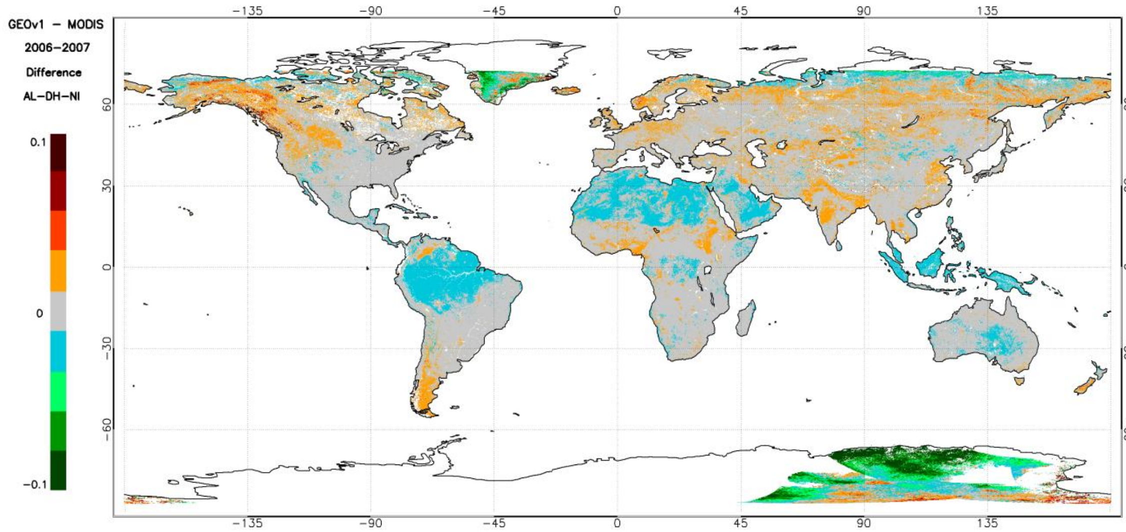

GEOv1 – MODIS
2006–2007
Difference
AL-BH-BB
0.1
0
−0.1
−135 −90 −45 0 45 90 135
60 30 0 −30 −60


GEOv1 – MODIS
2006–2007
Difference
AL-BH-VI
0.1
0
−0.1
−135 −90 −45 0 45 90 135
60 30 0 −30 −60

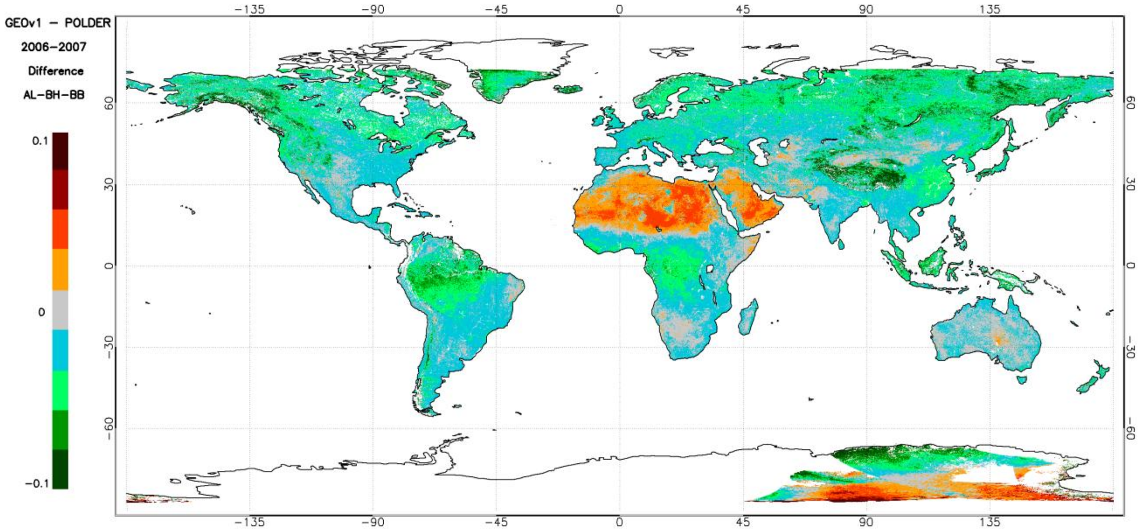

GEOv1 – MODIS
2006–2007
Difference
AL-BH-NI
0.1
0
−0.1
−135 −90 −45 0 45 90 135
60 30 0 −30 −60

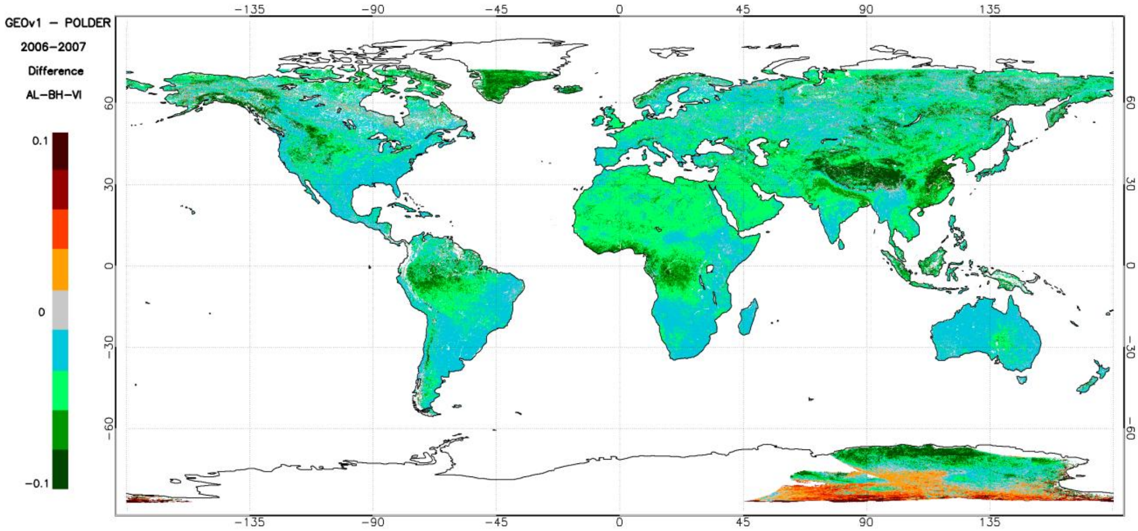


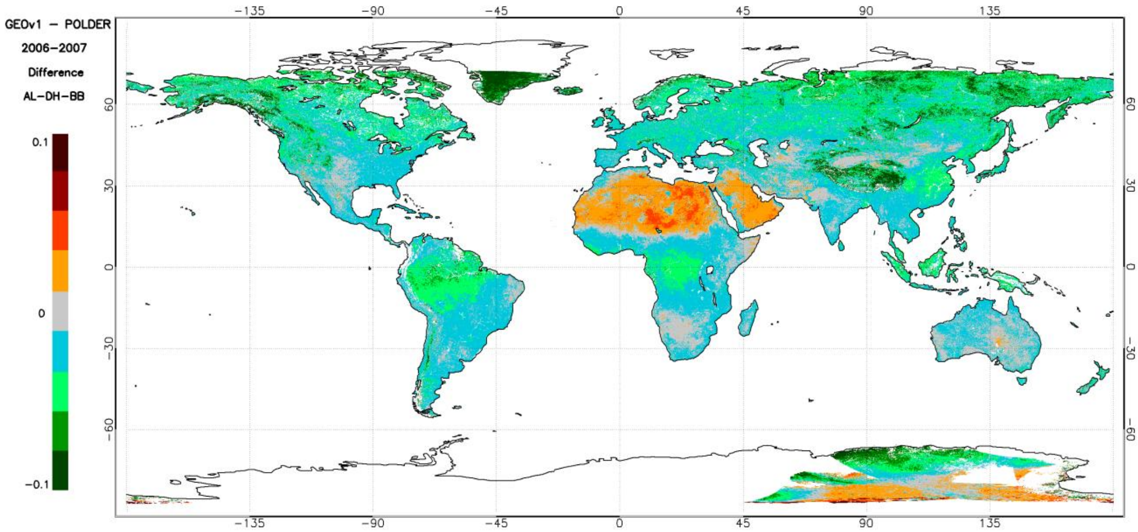


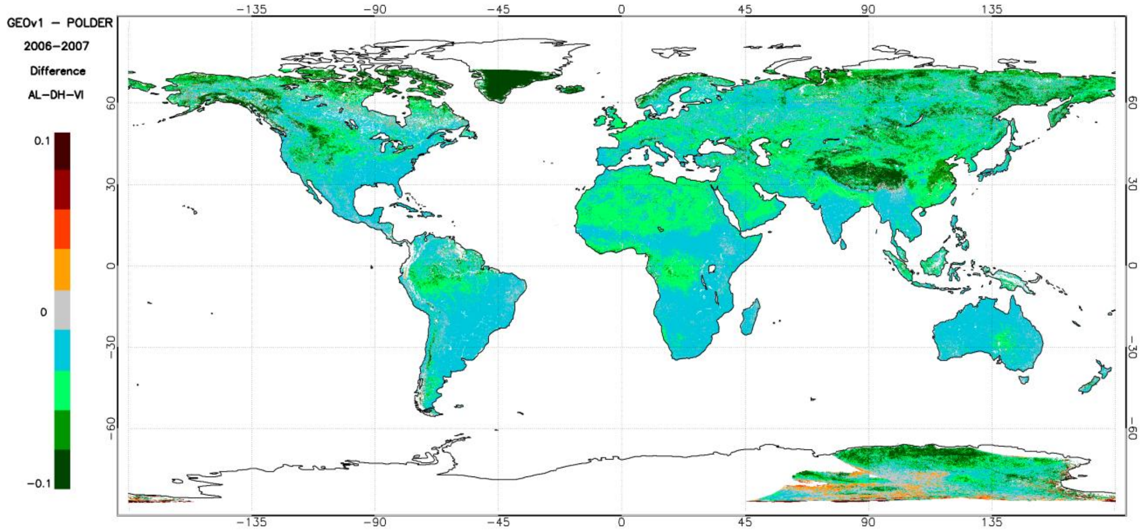


GEO vs POLDER

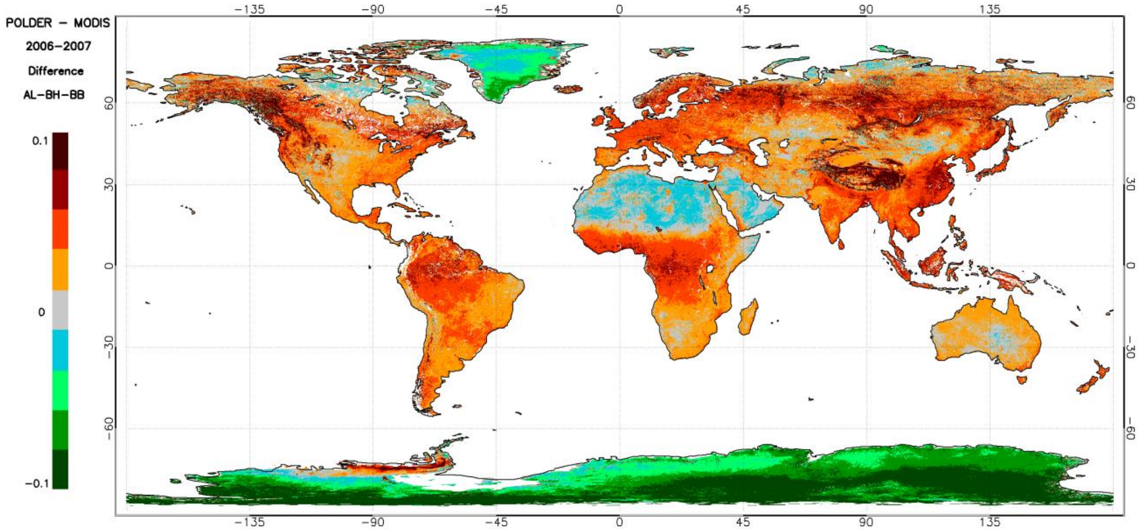

GEOv1 – POLDER
2006–2007
Difference
AL-BH-BB

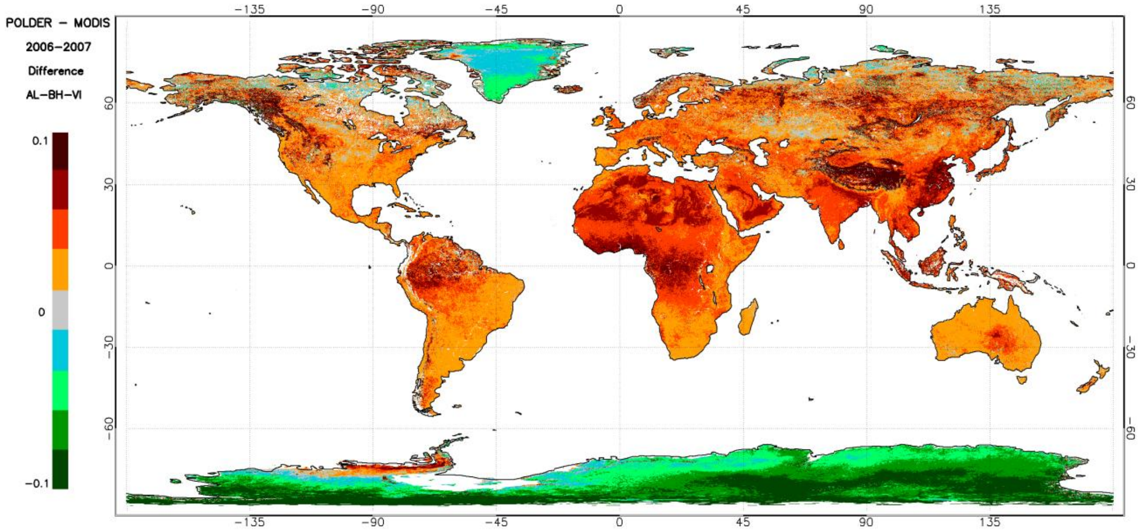

GEOv1 – POLDER
2006–2007
Difference
AL-BH-VI

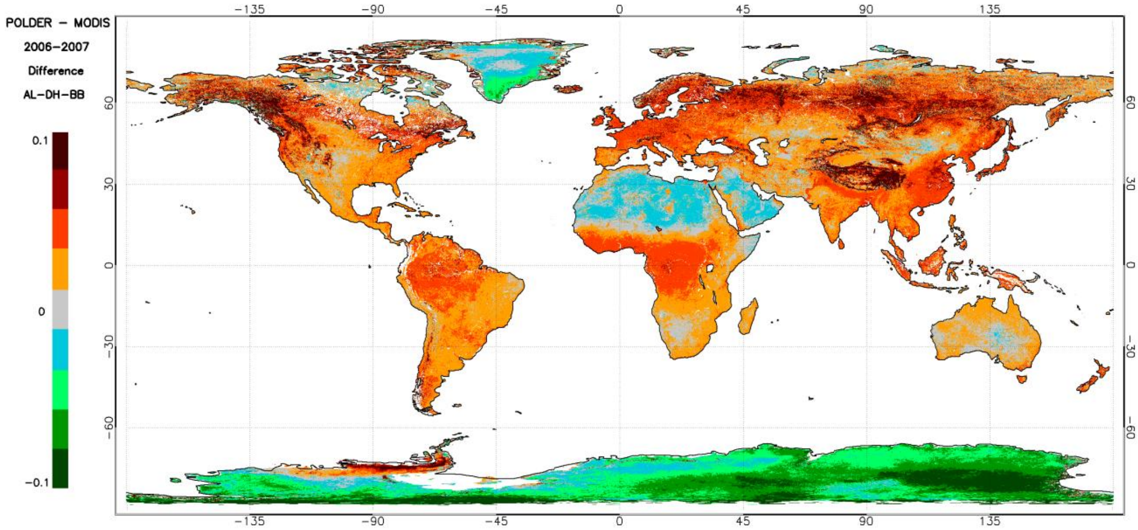

GEOv1 – POLDER
2006–2007
Difference
AL-DH-BB

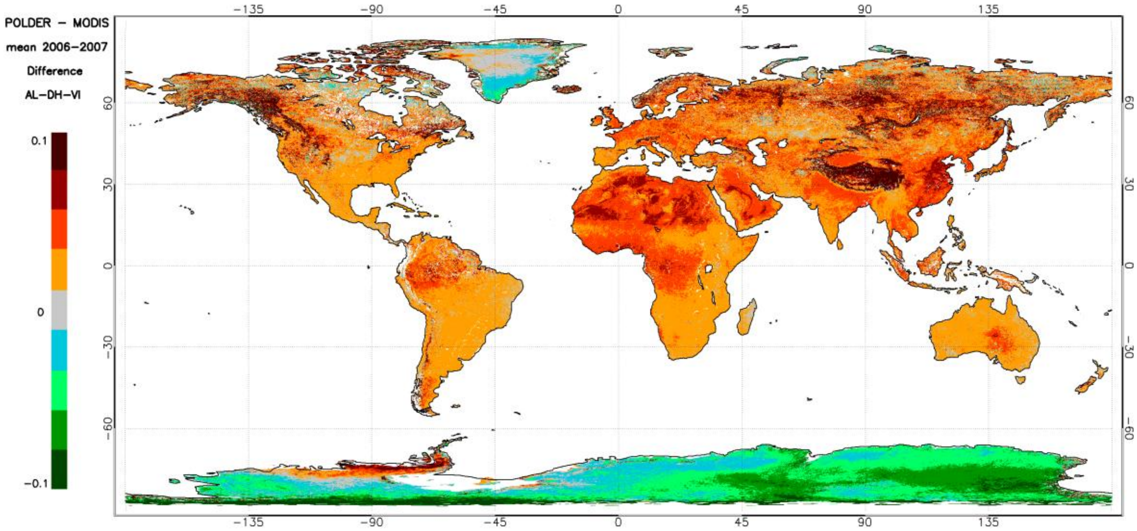

GEOv1 – POLDER
2006–2007
Difference
AL–DH–VI
0.1
0
–0.1
–135
–90
–45
0
45
90
135
60
30
0
–30
–60

POLDER vs MODIS








POLDER – MODIS
mean 2006–2007
Difference
AL–DH–VI
0.1
0
–0.1
–135
–90
–45
0
45
90
135
60
30
0
–30
–60

ANNEX B: PERFORMANCE METRICS OF THE GLOBAL INTERCOMPARISON OVER BELMANIP-2 SITES FOR THE 2006-2007 PERIOD

AL-DH-BB (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS
	All BELMANIP-2 sites		
R^2	0.9436	0.8592	0.8815
Bias	0.0058	-0.0149	0.0209
RMSE	0.0265	0.0436	0.0478
RMSEr	13.33	20.15	21.75
	Broadleaved Evergreen Forest		
R^2	0.5338	0.2873	0.4237
Bias	-0.0013	-0.0398	0.0379
RMSE	0.0106	0.0434	0.0406
RMSEr	8.95	30.89	29.03
	Broadleaved Deciduous Forest		
R^2	0.6766	0.1927	0.3523
Bias	0.0076	-0.0257	0.0336
RMSE	0.0126	0.0401	0.045
RMSEr	9.95	27.82	32.08
	Needle-leaved Forest		
R^2	0.9477	0.7285	0.7232
Bias	0.005	-0.0353	0.0494
RMSE	0.0214	0.0604	0.0808
RMSEr	16.64	39.94	48.81
	Cultivated		
R^2	0.91	0.8636	0.8961
Bias	0.0075	-0.0198	0.0264
RMSE	0.0303	0.039	0.0444
RMSEr	16.63	19.7	22.05
	Shrublands		
R^2	0.8913	0.855	0.9174
Bias	0.006	-0.0172	0.0212
RMSE	0.0273	0.0374	0.038
RMSEr	16.58	21	20.53
	Herbaceous		
R^2	0.9241	0.8649	0.9038
Bias	0.0023	-0.0128	0.0131
RMSE	0.0317	0.0453	0.0453
RMSEr	14.81	19.71	19.04
	Bare Areas		
R^2	0.9396	0.8282	0.8848
Bias	0.0096	0.0072	0.0012
RMSE	0.0256	0.0415	0.0346
RMSEr	8.33	13.28	11.24
	Snow		
R^2	0.9476	0.9184	0.9419
Bias	-0.0102	-0.0381	0.0079
RMSE	0.0615	0.0787	0.0767
RMSEr	21.84	25.2	17.22

AL-DH-VI (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS
	All BELMANIP-2 sites		
R^2	0.9248	0.88	0.8843
Bias	-0.0015	-0.0325	0.0316
RMSE	0.0398	0.0636	0.0627
RMSEr	31.37	41.75	40.73
	Broadleaved Evergreen Forest		
R^2	0.139	0.1549	0.168
Bias	0.0001	-0.0319	0.0287
RMSE	0.0106	0.0428	0.0394
RMSEr	41.78	98.89	97.18
	Broadleaved Deciduous Forest		
R^2	0.496	0.2198	0.3862
Bias	0.0035	-0.0253	0.0288
RMSE	0.0143	0.0474	0.0494
RMSEr	33.82	80.6	86.9
	Needle-leaved Forest		
R^2	0.9377	0.739	0.745
Bias	-0.001	-0.0264	0.0385
RMSE	0.0319	0.0757	0.0967
RMSEr	42.65	83.76	85.07
	Cultivated		
R^2	0.9133	0.8908	0.9205
Bias	-0.0017	-0.0316	0.0286
RMSE	0.046	0.0591	0.0531
RMSEr	40.66	45.1	40.23
	Shrublands		
R^2	0.9194	0.8973	0.9295
Bias	-0.0018	-0.0264	0.0236
RMSE	0.0407	0.0541	0.0474
RMSEr	38.57	44.62	37.32
	Herbaceous		
R^2	0.9174	0.8917	0.9078
Bias	-0.0059	-0.0337	0.0269
RMSE	0.0515	0.0717	0.0633
RMSEr	34.26	40.04	35.93
	Bare Areas		
R^2	0.8646	0.7732	0.8183
Bias	0.0014	-0.0413	0.0419
RMSE	0.0329	0.066	0.0603
RMSEr	14.94	26.76	24.79
	Snow		
R^2	0.9459	0.9294	0.953
Bias	-0.0343	-0.0461	0.0089
RMSE	0.0985	0.1093	0.0868
RMSEr	26.29	26.54	17.61

AL-DH-NI (X-Y)	GEOV1 MODIS
All BELMANIP-2 sites	
R^2	0.9615
Bias	-0.0008
RMSE	0.0224
RMSEr	8.4
Broadleaved Evergreen Forest	
R^2	0.6388
Bias	-0.014
RMSE	0.0208
RMSEr	10.95
Broadleaved Deciduous Forest	
R^2	0.7657
Bias	0.0004
RMSE	0.0162
RMSEr	8.39
Needle-leaved Forest	
R^2	0.884
Bias	0.006
RMSE	0.0213
RMSEr	12.22
Cultivated	
R^2	0.884
Bias	0.0017
RMSE	0.0232
RMSEr	9.25
Shrublands	
R^2	0.8812
Bias	0.0031
RMSE	0.0212
RMSEr	9.52
Herbaceous	
R^2	0.9388
Bias	-0.0002
RMSE	0.0241
RMSEr	8.55
Bare Areas	
R^2	0.9717
Bias	-0.0068
RMSE	0.0235
RMSEr	5.98
Snow	
R^2	0.9012
Bias	0.0102
RMSE	0.0531
RMSEr	18.03

AL-BH-BB (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS
All BELMANIP-2 sites			
R^2	0.9363	0.8458	0.8745
Bias	0.0082	-0.0139	0.0221
RMSE	0.0278	0.0445	0.0486
RMSEr	13.28	19.63	21.21
Broadleaved Evergreen Forest			
R^2	0.402	0.2201	0.3493
Bias	0.0024	-0.0449	0.0458
RMSE	0.0147	0.0515	0.0506
RMSEr	10.9	32.16	32.18
Broadleaved Deciduous Forest			
R^2	0.6256	0.2605	0.3707
Bias	0.0095	-0.0291	0.0386
RMSE	0.0163	0.0439	0.0508
RMSEr	11.74	27.95	33.21
Needle-leaved Forest			
R^2	0.9376	0.6982	0.7035
Bias	0.0037	-0.0375	0.0471
RMSE	0.0213	0.0612	0.0753
RMSEr	16.06	39.63	45.07
Cultivated			
R^2	0.8852	0.8246	0.868
Bias	0.0097	-0.0191	0.0279
RMSE	0.0318	0.0393	0.0473
RMSEr	16.41	18.81	22.35
Shrublands			
R^2	0.8687	0.8188	0.9051
Bias	0.0079	-0.017	0.0227
RMSE	0.0279	0.0372	0.0396
RMSEr	15.97	19.68	20.33
Herbaceous			
R^2	0.9097	0.8349	0.8891
Bias	0.0049	-0.01	0.0132
RMSE	0.032	0.0447	0.0467
RMSEr	14.24	18.65	18.91
Bare Areas			
R^2	0.9368	0.8267	0.8846
Bias	0.0141	0.0108	0.0025
RMSE	0.0285	0.0432	0.0345
RMSEr	8.92	13.32	10.84
Snow			
R^2	0.9401	0.9118	0.9382
Bias	-0.0106	-0.0291	0.0001
RMSE	0.0589	0.0701	0.0788
RMSEr	21.58	23.42	18.12

AL-BH-VI (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS
	All BELMANIP-2 sites		
R^2	0.9219	0.8629	0.8701
Bias	-0.0005	-0.036	0.0358
RMSE	0.0397	0.0666	0.0661
RMSEr	29.87	41.49	40.95
	Broadleaved Evergreen Forest		
R^2	0.1103	0.1129	0.1514
Bias	0.0021	-0.047	0.0441
RMSE	0.0134	0.063	0.0584
RMSEr	42.49	109.45	110.18
	Broadleaved Deciduous Forest		
R^2	0.4208	0.1792	0.3
Bias	0.0058	-0.034	0.0394
RMSE	0.017	0.0561	0.0606
RMSEr	35.77	81.14	91.63
	Needle-leaved Forest		
R^2	0.937	0.7185	0.7272
Bias	-0.001	-0.0283	0.0357
RMSE	0.0313	0.0764	0.0904
RMSEr	41.22	82.89	80.04
	Cultivated		
R^2	0.9071	0.869	0.8956
Bias	-0.0005	-0.0357	0.0335
RMSE	0.046	0.0633	0.06
RMSEr	39.02	45.79	43.28
	Shrublands		
R^2	0.9131	0.8796	0.9175
Bias	-0.0005	-0.0302	0.0285
RMSE	0.0404	0.0565	0.0517
RMSEr	36.64	43.93	38.72
	Herbaceous		
R^2	0.9129	0.8733	0.8919
Bias	-0.0044	-0.0344	0.0298
RMSE	0.0504	0.0728	0.0671
RMSEr	32.16	39.2	36.69
	Bare Areas		
R^2	0.8578	0.7627	0.8061
Bias	0.0016	-0.0442	0.046
RMSE	0.0341	0.0681	0.0637
RMSEr	14.73	26.3	24.91
	Snow		
R^2	0.9445	0.9277	0.9489
Bias	-0.028	-0.0259	-0.0022
RMSE	0.0927	0.0969	0.0897
RMSEr	25.01	24.12	18.66

AL-BH-NI (X-Y)	GEOV1 MODIS
All BELMANIP-2 sites	
R^2	0.955
Bias	0.0001
RMSE	0.0235
RMSEr	8.3
Broadleaved Evergreen Forest	
R^2	0.494
Bias	-0.0125
RMSE	0.0248
RMSEr	11.54
Broadleaved Deciduous Forest	
R^2	0.7548
Bias	-0.0006
RMSE	0.0199
RMSEr	9.43
Needle-leaved Forest	
R^2	0.8827
Bias	0.0025
RMSE	0.0197
RMSEr	10.93
Cultivated	
R^2	0.8499
Bias	0.0018
RMSE	0.0254
RMSEr	9.45
Shrublands	
R^2	0.8494
Bias	0.003
RMSE	0.0222
RMSEr	9.28
Herbaceous	
R^2	0.9233
Bias	0.0008
RMSE	0.0256
RMSEr	8.62
Bare Areas	
R^2	0.9692
Bias	-0.0009
RMSE	0.0225
RMSEr	5.5
Snow	
R^2	0.8938
Bias	0.0049
RMSE	0.0488
RMSEr	17.31

ANNEX C: PERFORMANCE METRICS OF THE REGIONAL INTERCOMPARISON OVER EUROPE/NORTH AFRICA FOR THE YEAR 2007

AL-DH-BB (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS	GEOV1 MSG	MODIS MSG	POLDER MSG
R^2	0.9663	0.9119	0.9262	0.9413	0.9248	0.8385
Bias	0.0071	-0.004	0.0114	0.0033	-0.0042	0.0069
RMSE	0.0223	0.0357	0.0366	0.0335	0.0365	0.055
RMSEr	8.56	13.24	13.72	12.75	14	20.36
Broadleaved Deciduous Forest						
R^2	0.7294	0.2486	0.3192	0.1185	0.159	0.1724
Bias	0.0094	-0.0277	0.0375	0.016	0.0042	0.0439
RMSE	0.0148	0.0433	0.0504	0.0284	0.026	0.0616
RMSEr	10.96	28.24	33.68	21.32	20.28	41.36
Needle-leaved Forest						
R^2	0.8481	0.4987	0.5595	0.1371	0.0337	0.3492
Bias	0.0087	-0.0369	0.0525	0.0255	0.0314	0.0647
RMSE	0.0183	0.0523	0.0762	0.0435	0.0771	0.0897
RMSEr	16.36	38.64	54.32	41.4	69.56	68.28
Cultivated						
R^2	0.565	0.3845	0.5629	0.4105	0.4338	0.3676
Bias	0.0113	-0.0223	0.0331	0.0202	0.0087	0.0433
RMSE	0.0301	0.046	0.0471	0.0388	0.0405	0.0684
RMSEr	18	24.88	26.2	23.59	25.44	38.04
Shrublands						
R^2	0.8224	0.7037	0.694	0.4027	0.3387	0.4351
Bias	0.0075	-0.017	0.0242	0.014	0.0037	0.0249
RMSE	0.0209	0.0329	0.0396	0.0411	0.0432	0.0472
RMSEr	12.08	17.38	21.32	23.45	25.44	25.44
Herbaceous						
R^2	0.941	0.8854	0.8735	0.8345	0.871	0.7524
Bias	0.0033	-0.005	0.0093	-0.002	-0.0064	0.0014
RMSE	0.0165	0.023	0.0265	0.0335	0.031	0.0408
RMSEr	6.48	8.8	10.2	12.81	12.12	15.44
Bare Areas						
R^2	0.9501	0.9406	0.9688	0.8933	0.9497	0.9341
Bias	0.0041	0.0179	-0.0132	-0.0152	-0.0208	-0.0337
RMSE	0.0144	0.0242	0.0169	0.0253	0.025	0.0379
RMSEr	3.84	6.52	4.6	6.51	6.48	9.96

AL-DH-VI (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS	GEOV1 MSG	MODIS MSG	POLDER MSG
R^2	0.9259	0.8758	0.8966	0.9098	0.8121	0.8002
Bias	0.0022	-0.0387	0.0411	-0.018	-0.0189	0.0209
RMSE	0.0266	0.0544	0.0543	0.0401	0.0534	0.0562
RMSEr	17.48	30.84	30.88	24.44	32.48	29.8
			Broadleaved Deciduous Forest			
R^2	0.8034	0.3054	0.3211	0.2757	0.3231	0.2817
Bias	0.0023	-0.0275	0.0298	-0.013	-0.0148	0.0158
RMSE	0.0123	0.0523	0.0557	0.0282	0.032	0.0586
RMSEr	31.24	95.44	103.52	59.96	69.2	93.08
			Needle-leaved Forest			
R^2	0.9088	0.5524	0.5851	0.4337	0.1789	0.4621
Bias	-0.001	-0.0285	0.0356	-0.0018	0.0233	0.033
RMSE	0.0174	0.0574	0.084	0.0319	0.0903	0.0889
RMSEr	43.4	106.28	121.96	86.47	155.12	140.64
			Cultivated			
R^2	0.5211	0.3959	0.6143	0.488	0.4283	0.4728
Bias	-0.0012	-0.0359	0.0334	0.0006	0.0041	0.0393
RMSE	0.0385	0.0655	0.0549	0.0385	0.0545	0.0797
RMSEr	50.76	69.12	57.36	48.72	67.72	77.92
			Shrublands			
R^2	0.8953	0.7943	0.708	0.4789	0.3873	0.5673
Bias	0.0016	-0.029	0.0299	0.0016	-0.003	0.0255
RMSE	0.0213	0.0478	0.0517	0.0418	0.0472	0.0529
RMSEr	25.08	45.28	49.76	47.91	54.44	49.64
			Herbaceous			
R^2	0.9342	0.8757	0.8869	0.8634	0.8456	0.8126
Bias	-0.0033	-0.0372	0.0341	-0.0201	-0.0159	0.0163
RMSE	0.0174	0.045	0.0418	0.0369	0.0379	0.0377
RMSEr	11.4	25.8	24.12	22.28	23.68	20.44
			Bare Areas			
R^2	0.9494	0.9566	0.9315	0.863	0.8557	0.9093
Bias	0.0078	-0.0437	0.0519	-0.039	-0.0479	0.004
RMSE	0.0133	0.0451	0.0539	0.0436	0.0521	0.0165
RMSEr	5.4	16.56	20.08	16.07	19.48	5.64

AL-DH-NI (X-Y)	GEOV1 MODIS	GEOV1 MSG	MODIS MSG
R^2	0.9765	0.9426	0.9458
Bias	-0.007	-0.0053	-0.0008
RMSE	0.0237	0.0381	0.0348
RMSEr	6.72	10.81	9.76
	Broadleaved Deciduous Forest		
R^2	0.7488	0.2772	0.2435
Bias	0.0017	0.0144	0.0072
RMSE	0.0205	0.0318	0.0348
RMSEr	9.8	15.41	17.08
	Needle-leaved Forest		
R^2	0.6555	0.006	0.0088
Bias	0.0087	0.0274	0.0305
RMSE	0.0231	0.0543	0.0772
RMSEr	13.88	33.61	48.16
	Cultivated		
R^2	0.697	0.3945	0.4912
Bias	0.0019	0.0125	0.0066
RMSE	0.0235	0.0378	0.0357
RMSEr	9.64	15.81	15.04
	Shrublands		
R^2	0.7799	0.3961	0.3198
Bias	0.0018	-0.0035	-0.0082
RMSE	0.0218	0.046	0.0511
RMSEr	8.92	18.08	20.36
	Herbaceous		
R^2	0.9432	0.8183	0.8315
Bias	-0.0099	-0.0132	-0.0061
RMSE	0.0212	0.0398	0.0365
RMSEr	6.16	11.41	10.4
	Bare Areas		
R^2	0.9422	0.8873	0.9379
Bias	-0.0172	-0.0249	-0.0098
RMSE	0.025	0.0353	0.0214
RMSEr	5.08	7.09	4.24

AL-BH-BB (X-Y)	GEOv1 MODIS	GEOv1 POLDER	POLDER MODIS	GEOv1 MSG	MODIS MSG	POLDER MSG
R^2	0.9678	0.9189	0.9318	0.9454	0.9305	0.8622
Bias	0.0086	-0.0031	0.0121	0.0021	-0.0054	0.0054
RMSE	0.0227	0.0363	0.0362	0.0319	0.0359	0.0523
RMSEr	8.4	13	13.16	11.75	13.4	18.76
	Broadleaved Deciduous Forest					
R^2	0.8256	0.3819	0.4169	0.3068	0.3315	0.2497
Bias	0.008	-0.0304	0.0387	0.013	0.0037	0.0433
RMSE	0.0137	0.0453	0.0513	0.0277	0.0265	0.0604
RMSEr	9.68	28.36	32.6	19.9	19.76	38.68
	Needle-leaved Forest					
R^2	0.8848	0.476	0.5228	0.2913	0.0378	0.3375
Bias	0.0052	-0.0403	0.0514	0.0187	0.0276	0.0619
RMSE	0.0138	0.0542	0.0735	0.0354	0.0679	0.084
RMSEr	12.24	39.96	52.04	33.66	62.32	63.48
	Cultivated					
R^2	0.6016	0.4372	0.5826	0.5199	0.4641	0.3753
Bias	0.0109	-0.0224	0.033	0.0162	0.0071	0.0396
RMSE	0.0304	0.0452	0.0469	0.0372	0.0416	0.0647
RMSEr	17.36	23.64	25.08	21.83	25.12	34.76
	Shrublands					
R^2	0.8686	0.7063	0.7055	0.5269	0.5086	0.5113
Bias	0.0064	-0.0194	0.0258	0.007	-0.0008	0.0219
RMSE	0.0186	0.0335	0.0401	0.0386	0.04	0.045
RMSEr	10.36	17.08	20.68	21.48	22.92	23
	Herbaceous					
R^2	0.9483	0.8883	0.7055	0.8447	0.8877	0.7898
Bias	0.0032	-0.006	0.0258	-0.0071	-0.0095	-0.0021
RMSE	0.0161	0.0237	0.0401	0.0339	0.0306	0.0389
RMSEr	6.08	8.72	20.68	12.46	11.56	14.12
	Bare Areas					
R^2	0.9543	0.9338	0.9603	0.8812	0.9407	0.919
Bias	0.0088	0.0208	-0.0115	-0.0113	-0.0205	-0.0322
RMSE	0.0161	0.0269	0.0163	0.0239	0.0251	0.0366
RMSEr	4.12	6.96	4.28	5.94	6.32	9.36

AL-BH-VI (X-Y)	GEOV1 MODIS	GEOV1 POLDER	POLDER MODIS
R^2	0.9296	0.887	0.9002
Bias	0.0017	-0.0417	0.0436
RMSE	0.0269	0.0563	0.0566
RMSEr	16.88	30.52	30.8
	Broadleaved Deciduous Forest		
R^2	0.7701	0.2522	0.2697
Bias	0.0022	-0.0314	0.0341
RMSE	0.0131	0.0552	0.0584
RMSEr	31.12	93.8	100
	Needle-leaved Forest		
R^2	0.9088	0.5177	0.5558
Bias	-0.0022	-0.0295	0.034
RMSE	0.0172	0.0582	0.0804
RMSEr	42.4	107.32	117.52
	Cultivated		
R^2	0.5158	0.3851	0.5796
Bias	-0.0018	-0.0371	0.0346
RMSE	0.0383	0.0648	0.0558
RMSEr	48.56	66.24	56.08
	Shrublands		
R^2	0.8968	0.7828	0.7149
Bias	0.0007	-0.0325	0.0328
RMSE	0.021	0.0497	0.0524
RMSEr	23.88	44.88	47.72
	Herbaceous		
R^2	0.9352	0.8756	0.8921
Bias	-0.0053	-0.042	0.0365
RMSE	0.0185	0.0499	0.0445
RMSEr	11.52	27.28	24.4
	Bare Areas		
R^2	0.9331	0.9412	0.9118
Bias	0.0079	-0.0477	0.0561
RMSE	0.0146	0.0495	0.0584
RMSEr	5.68	17.32	20.72

AL-BH-NI (X-Y)	GEOv1 MODIS
R^2	0.9784
Bias	-0.0058
RMSE	0.0218
RMSEr	5.96
Broadleaved Deciduous Forest	
R^2	0.8512
Bias	-0.0026
RMSE	0.0215
RMSEr	9.76
Needle-leaved Forest	
R^2	0.7193
Bias	0.0026
RMSE	0.0168
RMSEr	10
Cultivated	
R^2	0.793
Bias	-0.0003
RMSE	0.0237
RMSEr	9.24
Shrublands	
R^2	0.8584
Bias	-0.0008
RMSE	0.0191
RMSEr	7.52
Herbaceous	
R^2	0.9437
Bias	-0.0104
RMSE	0.0219
RMSEr	6.12
Bare Areas	
R^2	0.9462
Bias	-0.0109
RMSE	0.0205
RMSEr	4.04

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