EUMETSAT Satellite Application Facility on Climate Monitoring

The EUMETSAT Network of Satellite Application Facilities

CM SAF Climate Monitoring

Validation Report
CM SAF MSG Surface Albedo
Edition 1

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Reference Documents

Reference	Title	Code
RD 1	Product User Manual	SAF/CM/FMI/PUM/SEV/SAL/1.2
RD 2	Algorithm Theoretical Basis Document CLAAS-SAL	SAF/CM/FMI/ATBD/SEV/SAL/1.2
RD 3	Validation Report CM SAF Clouds, Albedo and Radiation Surface Albedo (CLARA-SAL)	SAF/CM/FMI/VAL/GAC/SAL/1.2

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1. Executive Summary

This CM SAF report provides information on the validation of the CM SAF edition 1 data set derived from Spinning Enhanced Visible Infra-Red Imager (SEVIRI) observations on board Meteosat Second Generation satellites.

The shortwave surface albedo, the ratio of reflected solar flux to the incoming solar flux, is an important driver of the surface energy budget of the Earth. Variations and trends in surface albedo can influence near-surface air temperatures as well as the melt-freeze cycles of sea ice and snow cover.

This report presents an evaluation of the dataset of

Broadband Surface Albedo [CM-61, SAL_SEVIRI_disk_DS]

covering the years 2004-2011. The dataset is henceforth referred to by as CM SAF Cloud property dAtAset Using SEVIRI, Surface ALbedo. (CLAAS-SAL).

The validation of the CLAAS-SAL algorithm is performed in two parts. First we evaluate the product accuracy against ground observations of surface albedo, while keeping in mind the problem of spatial representativeness of a point-like station observation versus large-scale satellite retrieval. The issue of representativeness on a global scale is explored with a comparison of CLAAS-SAL to existing global surface black-sky albedo products from MODIS MCD43C3 edition 5 products for year 2009.

The validation results show that CLAAS-SAL mostly achieves its target accuracy of 25% relative to reference observation. In the cases where the target is not met, the cause is found to generally be in the spatial representativeness of point-like ground measurements against the 0.05 degree satellite product (e.g. uniform snow cover at validation site vs. partial snow cover in the satellite product grid cell containing the site). Compared to the CLARA-A1-SAL (RD 3) product from AVHRR with 0.25 degree resolution, the 0.05 degree CLAAS-SAL conforms better with in situ measurements at Payerne, a common validation site for both datasets. This points toward the increased spatial resolution improving representativeness between in situ and satellite data, as can be expected.

A summary of the validation results is shown in Table 1. The table contains the mean relative retrieval error calculated from the monthly mean product results of the 3 validation sites. The stability (maximum deviation of retrieved monthly mean albedo from its 8-year mean, in relative units) is calculated from the regional mean albedo of Schwarzwald forest. We note that due to the short time span of the dataset, this indicator should be considered as a **first estimate of the “decadal” stability** of the data.

Table 1: Validation result summary

Mean absolute retrieval error (all sites, full period)	**10.98 %**
Mean RMSE (all sites, full period)	**0.046**
Stability over Schwarzwald (2004-2011, in relative units)	**8.75% / 8 years**

2. The EUMETSAT SAF on Climate Monitoring

The importance of climate monitoring with satellites was recognized in 2000 by EUMETSAT Member States when they amended the EUMETSAT Convention to affirm that the EUMETSAT mandate is also to "contribute to the operational monitoring of the climate and the detection of global climatic changes". Following this, EUMETSAT established within its Satellite Application Facility (SAF) network a dedicated centre, the SAF on Climate Monitoring (CM SAF, http://www.cmsaf.eu).

The consortium of CM SAF currently comprises the Deutscher Wetterdienst (DWD) as host institute, and the partners from the Royal Meteorological Institute of Belgium (RMIB), the Finnish Meteorological Institute (FMI), the Royal Meteorological Institute of the Netherlands (KNMI), the Swedish Meteorological and Hydrological Institute (SMHI), the Meteorological Service of Switzerland (MeteoSwiss), and the Meteorological Service of the United Kingdom (UK MetOffice). Since the beginning in 1999, the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) has developed and will continue to develop capabilities for a sustained generation and provision of Climate Data Records (CDR's) derived from operational meteorological satellites.

In particular the generation of long-term data sets is pursued. The ultimate aim is to make the resulting data sets suitable for the analysis of climate variability and potentially the detection of climate trends. CM SAF works in close collaboration with the EUMETSAT Central Facility and liaises with other satellite operators to advance the availability, quality and usability of Fundamental Climate Data Records (FCDRs) as defined by the Global Climate Observing System (GCOS). As a major task the CM-SAF utilizes FCDRs to produce records of Essential Climate Variables (ECVs) as defined by GCOS. Thematically, the focus of CM SAF is on ECVs associated with the global energy and water cycle.

Another essential task of CM SAF is to produce data sets that can serve applications related to the new Global Framework of Climate Services initiated by the WMO World Climate Conference-3 in 2009. CM SAF is supporting climate services at national meteorological and hydrological services (NMHSs) with long-term data records but also with data sets produced close to real time that can be used to prepare monthly/annual updates of the state of the climate. Both types of products together allow for a consistent description of mean values, anomalies, variability and potential trends for the chosen ECVs. CM SAF ECV data sets also serve the improvement of climate models both at global and regional scale.

As an essential partner in the related international frameworks, in particular WMO SCOPE-CM (Sustained COordinated Processing of Environmental satellite data for Climate Monitoring), the CM SAF - together with the EUMETSAT Central Facility, assumes the role as main implementer of EUMETSAT's commitments in support to global climate monitoring. This is achieved through:

- Application of highest standards and guidelines as lined out by GCOS for the satellite data processing,
- Processing of satellite data within a true international collaboration benefiting from developments at international level and pollinating the partnership with own ideas and standards,
- Intensive validation and improvement of the CM SAF climate data records,

- Taking a major role in data set assessments performed by research organisations such as WCRP. This role provides the CM SAF with deep contacts to research organizations that form a substantial user group for the CM SAF CDRs,
- Maintaining and providing an operational and sustained infrastructure that can serve the community within the transition of mature CDR products from the research community into operational environments.

A catalogue of all available CM SAF products is accessible via the CM SAF webpage, www.cmsaf.eu/. Here, detailed information about product ordering, add-on tools, sample programs and documentation is provided.

3. Introduction

Shortwave surface albedo is defined as the ability of a surface to reflect solar radiation, i.e. it is the ratio of the reflected shortwave solar flux to the incoming one. The albedo of natural surfaces varies from ~5-6% (water, concrete) up to 90% (fresh, small-grained snow). Determination of the Earth's surface energy budget is dependent on our ability to accurately and robustly monitor global surface albedo. Thus, climate change studies require information about surface albedo and its changes. This has been acknowledged by GCOS in through naming surface albedo as an Essential Climate Variable (ECV). Because the non-reflected solar radiation is absorbed and converted to heat energy, surface albedo and its variations also play a part in determining near-surface air temperatures.

The purpose of this document is to describe the procedures and results of the validation of this dataset against reference observations of surface albedo. The validation period was 2004-2011, but depending on availability of reference data on a site-by-site basis (see section 4.1). This document is divided as follows; first we shall introduce the validation reference datasets and the main characteristics of the CLAAS-SAL dataset. More details on the product generation procedure and applied algorithms are available in the CLAAS-SAL Product User Manual [RD 1] and the Algorithm Theoretical Basis Document [RD 2]. Then we shall present the validation results per reference data source with a brief discussion. After all the results have been shown, we shall then discuss the dataset quality as a whole, identify issues in the data for correction in future editions, and conclude with the main findings of the validation study.

4. CLAAS-SAL main characteristics and the validation process

The CLAAS-SAL is a shortwave black-sky surface albedo product, defined for the waveband of 300-4000 nm. Broadly speaking, the product generation process is as follows (details in ATBD [RD 2]):

- Inputs are the SEVIRI VIS0.6, VIS0.8, solar/satellite geometry, cloud mask, geolocation, and land cover data from the NWC-SAF software. The solar channel reflectances have been recalibrated using a method developed at KNMI.
- The atmospheric effects in the observed reflectance are removed with the SMAC algorithm (Rahman and Dedieu, 1994). Aerosols are handled by setting AOD at 550 nm at a constant level of 0.1.
- The surface reflectances are expanded into hemispherical spectral albedos by applying a BRDF algorithm based on the work of Roujean et al. (1992) and Wu et al. (1995). Snow BRDF effects are averaged temporally, no instantaneous correction is applied.
- The spectral albedos are processed to shortwave broadband albedos via a narrow-to-broadband (NTB) conversion (van Leeuwen and Roujean, 2002). The conversion is both instrument and pixel land cover specific. The land cover information comes from USGS land use classification data. Open water albedo is derived from a LUT by Jin et al. (2004). Currently the open water albedo depends only on SZA and is normalized to 60 degrees everywhere; thus the ocean albedo is constant at 0.0676.

The instantaneous products are then reprojected on a 0.05 degree global WGS84 latitude-longitude grid. The products are then temporally averaged to 5-day (pentad) and monthly means. The time-averaged SAL products have a target accuracy, defined as deviation from time-averaged in situ albedo, of 25% relative.

An example of the CLAAS-SAL end products is shown in Figure 1.

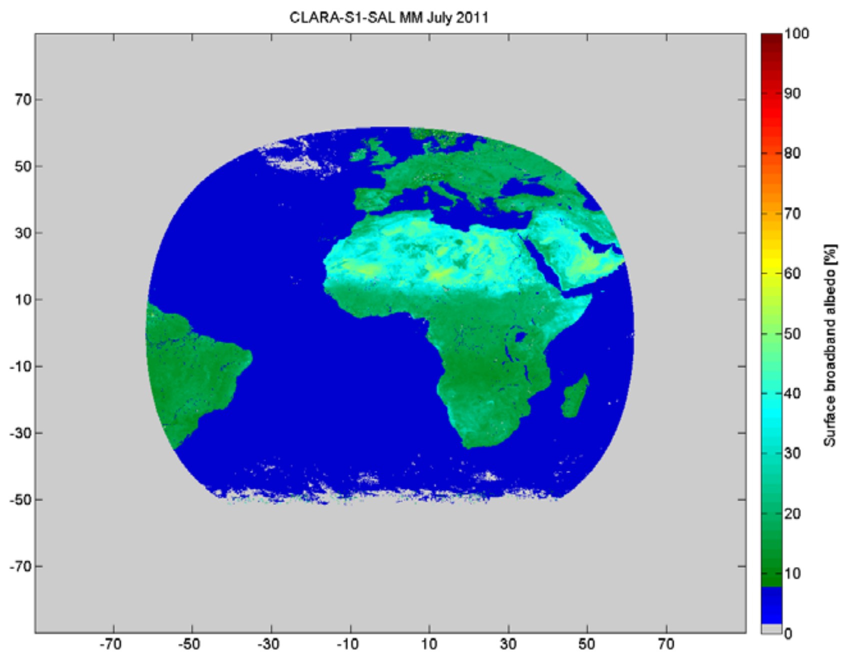

Figure 1: CLAAS-SAL monthly mean from July, 2011.

4.1. Validation Data Sets

The reference data used needs to be quality-controlled and have a sufficient data length to provide a meaningful comparison against the satellite time series. Radiative flux data from ground measurement stations listed in Table 2 were used as reference. The choice of stations was done by practical reasons; only a fraction of the solar radiation monitoring stations worldwide record the reflected shortwave radiation necessary to calculate the surface albedo, and of them, only some are located within the SEVIRI retrievable area. The ARM Mobile Facility in Niamey was selected to gain at least some quality-controlled validation data from Africa.

Table 2: validation sites used in validation

Station name / location	Latitude (N)	Longitude (E)	Land use type	Time period
Payerne, Switzerland (BSRN)	46.82	6.95	cultivated, hilly	2004-2009
Lindenberg, Germany (DWD)	52.10	14.40	grass, flat	2004-2011
ARM Mobile Facility Niamey, Nigeria	13.48	2.17	sand, soil	2006

The Payerne data, provided by the BSRN network, was composed of 1-minute average reflected and incoming solar radiation fluxes. The data was not explicitly versioned, but may be tracked with DOI codes. For example, the DOI for 2007 Payerne data was doi:10.1594/PANGAEA.762025. Data on the instruments used etc. may be found following the DOI.

The Lindenberg data was provided by DWD. The dataset was composed of 10-minute averages of reflected and incoming solar radiation fluxes. The dataset did not contain specific versioning or other metadata. However, the instrument characteristics and maintenance protocols of the data are viewable at http://www.dwd.de/mol. The site follows regular maintenance and calibration protocols of its instruments.

The Niamey data was provided by the ARM program of US Department of Energy. The dataset was composed of 1-minute average measurements of reflected and incoming solar radiation fluxes. The processing level of the data was b1. For a more detailed dataset description, the reader is referred to McFarlane et al. (2009).

All the reference site albedo measurements follow regular maintenance protocols; we estimate accuracy at Lindenberg and Payerne accuracy to conform to the typically given BSRN flux measurement uncertainty of 1-2% (relative). The Niamey site is not quite as stringently controlled, but following McFarlane et al. (2009), we take the flux uncertainty to be 2-3% (relative, from an reported 9 W/m2 uncertainty).

In addition, the temporal stability of the dataset was assessed at two sites; the Libyan desert site at 29.1 N, 24.5 E, previously used by Govaerts and Lattanzio (2007) as a calibration study target, and Schwarzwald forest (48N, 8E) as one of the few larger continuous forest areas in Central Europe. The validation and stability assessment sites are shown in Figure 2.

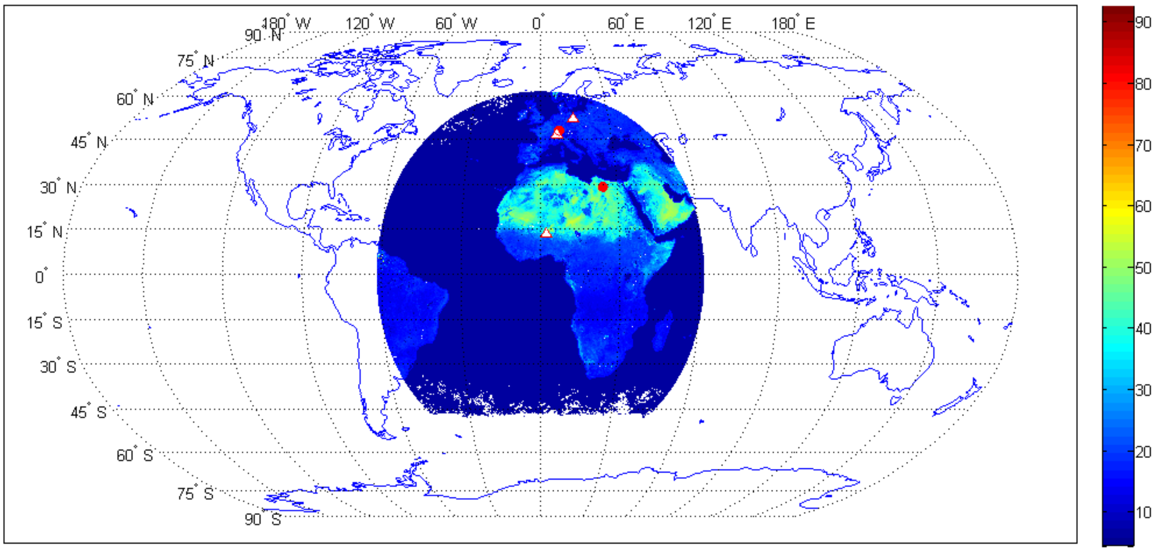

Figure 2: Validation sites (white triangles) and stability assessment sites (red circles) marked on an overlay of CLAAS-SAL data.

4.2. Validation methods

Since surface albedo of many natural surfaces is affected by cloudiness, it is desirable to construct the temporal means of reference observations from only those points in time for which there was a valid satellite retrieval of surface albedo. The CLAAS-SAL algorithm was preset to record its instantaneous retrieved albedo at validation sites on separate data files. However, the static viewing geometry and large pixel sizes led to missing or incomplete time stamps of instantaneous images. To obtain the required five-day or monthly in situ mean albedo, it was therefore decided to:

1) Use only ground measurements corresponding to successful instantaneous imaging timestamps if they exist, or…
2) use all ground measurements taken when Sun Zenith Angle < 70 degrees (to correspond with SAL algorithm) if the successful instantaneous imaging timestamps are missing

The resulting inaccuracy in our validation is of minor importance; It has been shown in several studies (e.g. Pinty et al. (2005)) that the ground-measurable blue-sky albedo (bihemispherical reflectance with non-isotropic incoming flux) of vegetation typically varies less than 0.01 as a function of cloudiness (i.e. increase in isotropic illumination). This uncertainty is comparable to the radiometric albedo retrieval uncertainty of the pyranometers at the validation sites.

There are issues in the comparability of reference in situ observations to satellite retrievals of surface albedo. First and foremost is the representativeness of a point-like observation of albedo at a ground site, when compared against a coarse resolution satellite retrieval (such as SEVIRI). Apart from stations deep on the Greenland Ice Sheet or Antarctica, the land cover surrounding the observation point is never homogeneous enough that one could comfortably say that the satellite observes only the same type of terrain as in the ground measurement.

A second issue in the data comparability is the inclusion of atmospheric effects in the reference albedo data. CLAAS-SAL is a black-sky albedo product, i.e. it is intended to produce the albedo of the Earth's surface in absence of any atmosphere. However, the irradiance (global solar radiation) recorded at reference sites invariably contains atmospheric effects that alter its spectral composition. This will alter the broadband albedo from its black-sky value. To achieve better comparability, the reference data would have to be corrected for the atmospheric effects on irradiance. However, information on aerosol, ozone or water vapour content of the atmosphere at validation sites is usually not available. Therefore we do not attempt to correct for these effects, but note that their effect may be considerable at sites where the atmosphere is optically thick either naturally (many coastal sites) or from anthropogenic reasons. A more detailed discussion on atmospheric effects in ground-based albedo measurements and the blue-sky/black-sky albedo comparability may be found in Manninen et al. (2012).

We define the following metrics for product evaluation: RMSE of the temporal mean satellite product vs. the temporal mean of reference data, mean relative retrieval error of satellite versus reference, and the mean absolute retrieval error of satellite versus reference. We include the mean absolute retrieval error as a metric to avoid the case where large negative and positive retrieval errors cancel each other out over the validation timeperiod, incorrectly improving the product performance. However, the mean relative retrieval error can still provide useful information on the product's tendency to over- or underestimate the in situ measured albedo, therefore we show both metrics. The CLAAS-SAL product has an accuracy requirement of 25% (relative to reference, NOT in albedo units.)

5. Validation against Station Observations

5.1. Payerne, Switzerland

The Baseline Surface Radiation Network (BSRN) site at Payerne, Switzerland, is located just outside the town of Payerne on a grass field. Use of this site in the CLARA-A1-SAL validation showed representativeness issues at the 0.25 degree resolution, likely because of the presence of a large lake - Lac de Neuchâtel - nearby. However, as the CLAAS-SAL we validate here has 5 times better resolution, there are grounds to think that the previous issues will be ameliorated.

The satellite and ground truth albedo values over the validation period are shown in Figure 3. The ground-measured albedo has greater variability, as can be expected considering its very small footprint. Occasional snowfall during winters creates spikes in the ground-measured albedo. These snowfall events are partly tracked by CLAAS-SAL, but clearly the coarser satellite resolution implies that a changing mixture of snow-covered and non-covered subregions within the 0.05 degree grid cell will bias the satellite albedo negatively relative to ground measurements (which are typically either of completely snow-free or completely snow-covered ground).

The relative retrieval errors of the monthly and pentad mean SAL products are shown in Figure 4, and numerically in Table 3 and Table 4. The monthly and pentad means fulfil the required 25% relative accuracy requirement for the product. Instantaneous retrievals until 2007 are of a grid cell identified as a water body, therefore its albedo is continuously negatively biased relative to validation site measurement. This changed in 2007, quite possibly as a result of the MSG satellite change. We further note that the validation results at Payerne are substantially better than those achieved for CLARA-A1-SAL [RD 3]. Analysis of those results showed that site representativeness issues were a likely cause of the poor performance of that dataset over Payerne. This is now further reinforced by the improved results obtained here using principally the same algorithm, but with a satellite data source yielding five times greater spatial resolution in the end products.

The instantaneous retrievals at a SEVIRI pixel closest to Payerne prior to 2007 are located to a water body, hence the low retrieved albedo (static 6.7%). During 2007, the location changed to a vegetation pixel. We assume that the MSG satellite turnover is the cause of this behaviour. As the 0.05 degree end product grid albedo is a mean of several SEVIRI pixels, this change has little apparent effect on monthly or pentad mean accuracy during either satellite's coverage period.

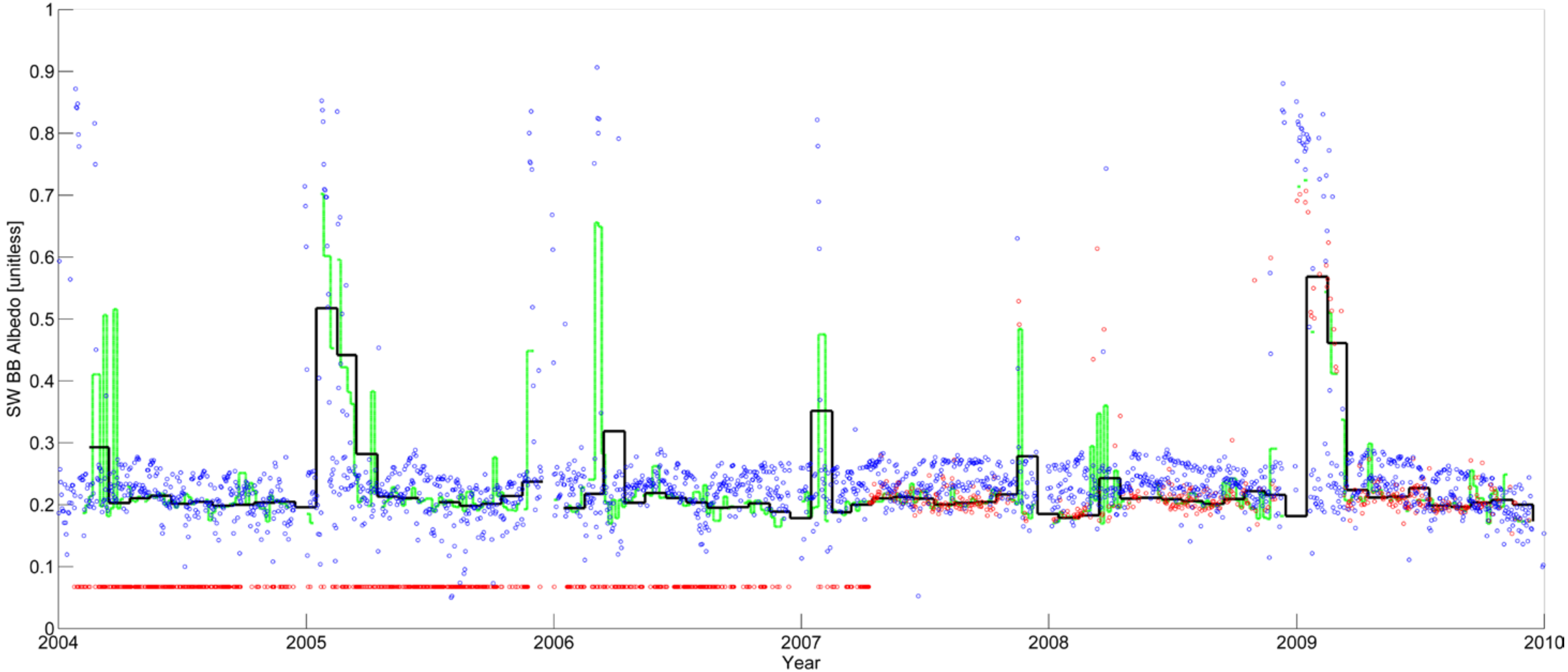

Figure 3: CLAAS-SAL and in situ albedo over Payerne between 2004-2009. Red circles indicate instantaneous in situ CLAAS-SAL retrievals closest to the site, blue circles show daily albedo means at the validation site, and the black (solid) and green (dashed) lines show the CLAAS-SAL monthly & pentad mean albedo, respectively.

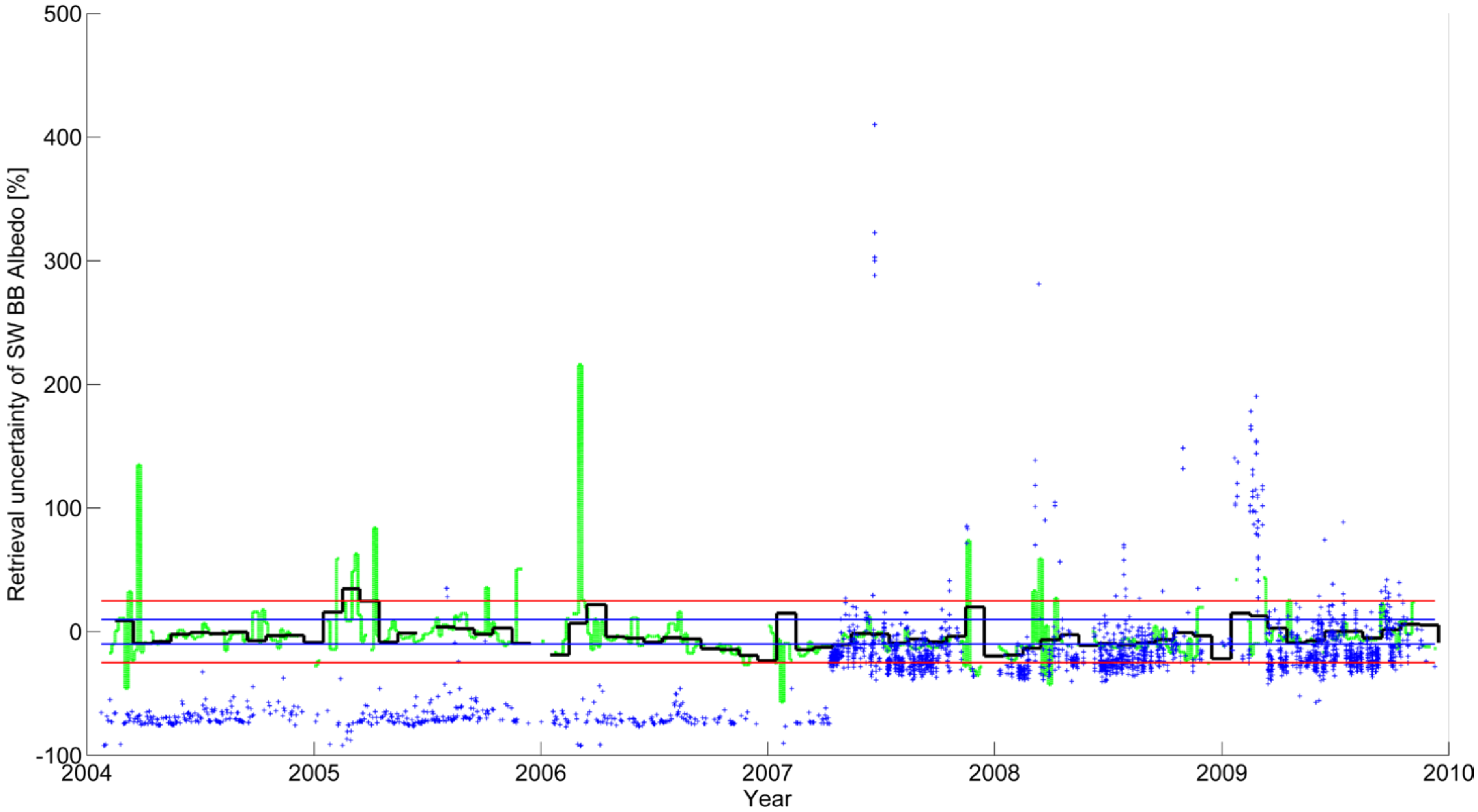

Figure 4: CLAAS-SAL relative retrieval error over Payerne. Blue crosses indicate retrieval errors at instantaneous level; the black and green lines show the retrieval error of the monthly and pentad mean (respectively). Red and blue dashed lines show 25% and 10% relative error levels.

Table 3: CLAAS-SAL product quality indicators at the monthly mean level over Payerne.

Dataset	RMSE	Mean rel. retrieval error [%]	Mean abs. retrieval error (relative to in situ) [%]	Notes
Instantaneous	0.143	-41.23	(46.15)	4425 retrievals. The „step“ in retrieval accuracy in 2007 likely related to MSG satellite change.
Monthly means	0.031	-3.08	8.94	N=69 (monthly means)
DJF	0.052	-2.42	16.08	N=16
MAM	0.025	-2.76	8.28	N=18
JJA	0.013	-3.88	4.68	N=17
SON	0.021	-3.23	7.27	N=18

Table 4: CLAAS-SAL product quality indicators at the pentad mean level over Payerne.

Dataset	RMSE	Mean rel. error [%]	Mean abs. retrieval error (relative to in situ) [%]	Notes
Pentad means	0.055	-2.91	12.77	N=304 (pentad means)
DJF	0.079	-9.32	18.03	N=56
MAM	0.076	3.15	16.71	N=88
JJA	0.018	-3.92	7.03	N=100
SON	0.037	-3.88	10.99	N=99

5.2. Lindenberg, Germany

The albedo measurements at Lindenberg validation site are carried out over a grass field patch, but the overall area around the site consists of forest-grassland mixture. The site has been routinely used in operational (EDR) SAL product validation; results have tended to show an underestimation of in situ albedo. As the CLAAS-SAL has greater spatial resolution and a new recalibration of reflectances, use of the site offers insight into the effects of spatial resolution and recalibration on SAL algorithm.

Figure 5 shows the validation and satellite data as a timeseries. Overall, there is no significant under- or overestimation in the spatiotemporal SAL means. Wintertime snowfall events are partly tracked; the reader should note that the SAL averaging in space and time and the representativeness of the validation site measurement over the larger area unavoidably affect retrieval precision.

Figure 6 shows the relative retrieval errors of the pentad and monthly mean CLAAS-SAL products. The accuracy requirement of the product is fulfilled, though we note a trend in the retrieval errors toward underestimations as time goes by. This has also been noted in the EDR-SAL validations and seems to be connected to a slight increasing trend in the in situ albedo. The satellite-derived albedo of the grid cell surrounding Lindenberg has remained quite stable (around ~0.2). Table 5 and Table 6 show the validation results in a numerical format.

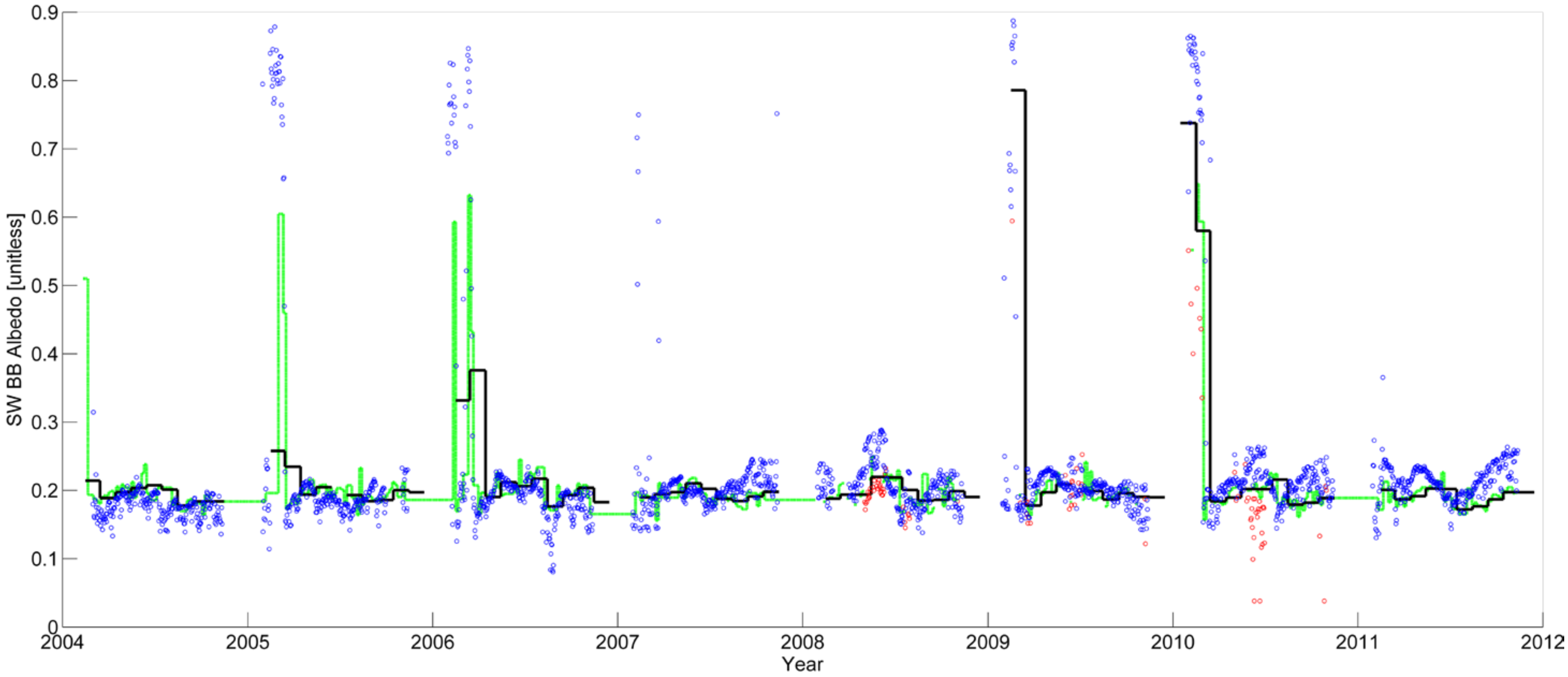

Figure 5: CLAAS-SAL and in situ albedo over Lindenberg. Blue circles indicate daily albedo means at the validation site, red circles indicate instantaneous CLAAS-SAL retrievals (if recorded), and the black and green (dashed) lines indicate the CLAAS-SAL monthly and pentad mean albedo, respectively.

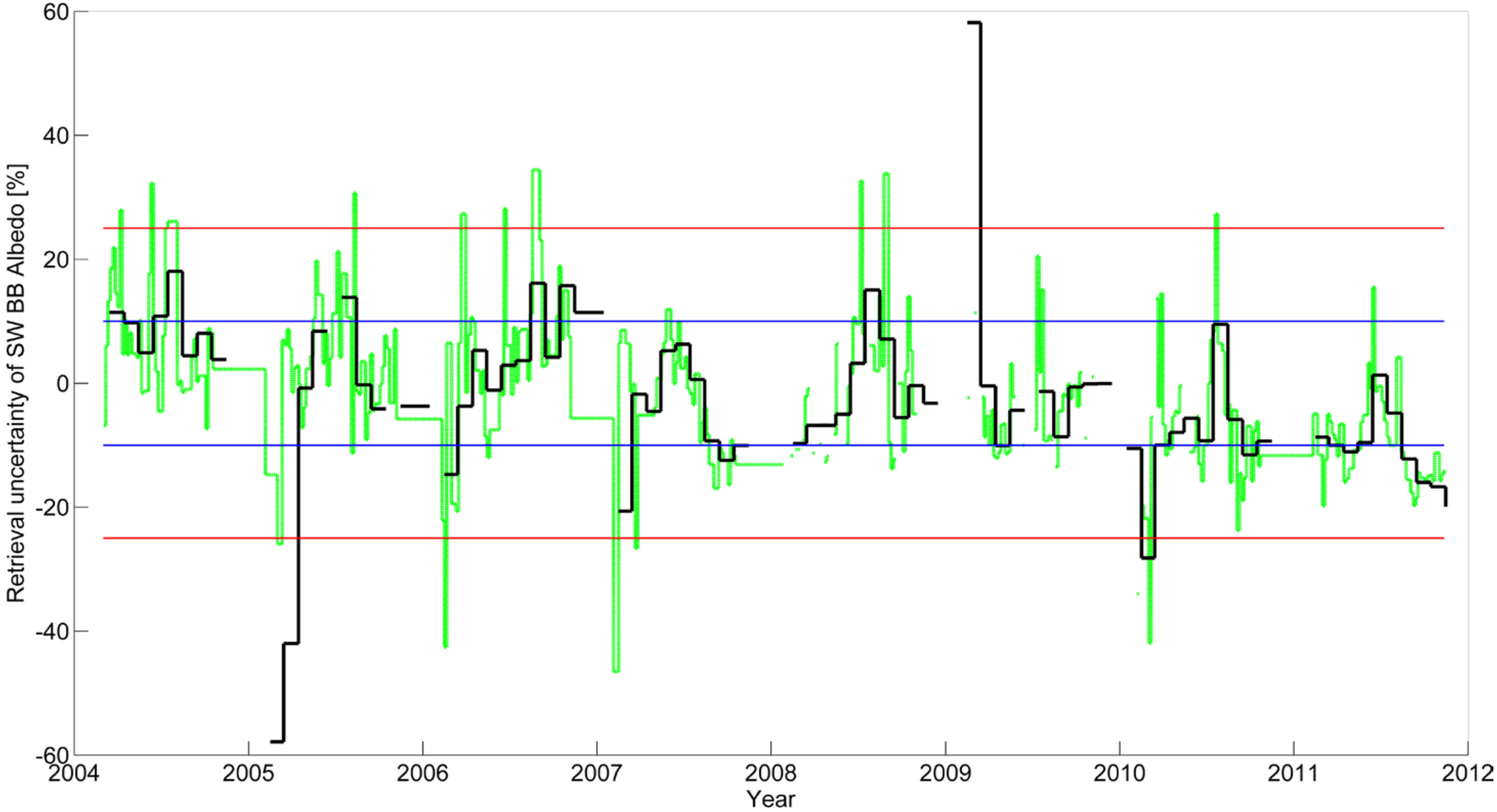

Figure 6: CLAAS-SAL relative retrieval error over Lindenberg. the black and green (dashed) lines indicate the retrieval error of the monthly and pentad means. Red dashed line shows 25% and the blue dashed line 10% relative error levels.

The product quality indicators at Lindenberg are listed in Table 5 and Table 6.

Table 5: CLAAS-SAL product quality indicators at the monthly mean level over Lindenberg.

Dataset / period	RMSE	Mean rel. error [%]	Mean abs. retrieval error (relative to in situ) [%]	Notes
Instantaneous	0.105	-28.75	29.42	402 retrievals
Monthly means	0.067	-2.66	9.68	N=74 (months)
DJF	0.185	-11.50	26.05	N=8
MAM	0.038	-4.01	7.77	N=24
JJA	0.016	2.80	7.49	N=22
SON	0.021	-3.52	7.84	N=20

Table 6: CLAAS-SAL product quality indicators at the pentad mean level over Lindenberg

Dataset / period	RMSE	Mean rel. error [%]	Mean abs. retrieval error (relative to in situ) [%]	Notes
Pentad means	0.037	-1.56	9.34	N=313 (pentad means)
DJF	0.087	-9.79	14.26	N=29
MAM	0.034	-1.94	8.89	N=117
JJA	0.021	2.45	2.45	N=129
SON	0.022	-3.89	9.03	N=105

5.3. Niamey ARM Mobile Facility, Nigeria

The US DoE Atmospheric Radiation Measurement (ARM) program's Mobile Facility was deployed to Niamey Airport, Nigeria, during 2006. The facility's measurements included broadband albedo over a sand/soil patch. The measurements have been described in detail by McFarlane et al. (2009). The measurements also included direct AOD retrievals, which showed that AOD loading over Niamey was often 0.5 or even more, especially during the first half of 2006. This will cause some difficulty for SAL retrievals, set at AOD=0.1.

Figure 7 shows the retrieved SAL monthly and pentad mean albedos versus the in situ measurements. As explained by McFarlane et al. (2009), the site albedo is highly variable over the summer (wet) period as a result of precipitation impacts on sand/soil albedo. This variation is difficult to accurately follow owing to its rapid changes, but it is clear that the large AOD loading biases SAL positively during this period. This is reflected in the relative retrieval errors shown in Figure 8.

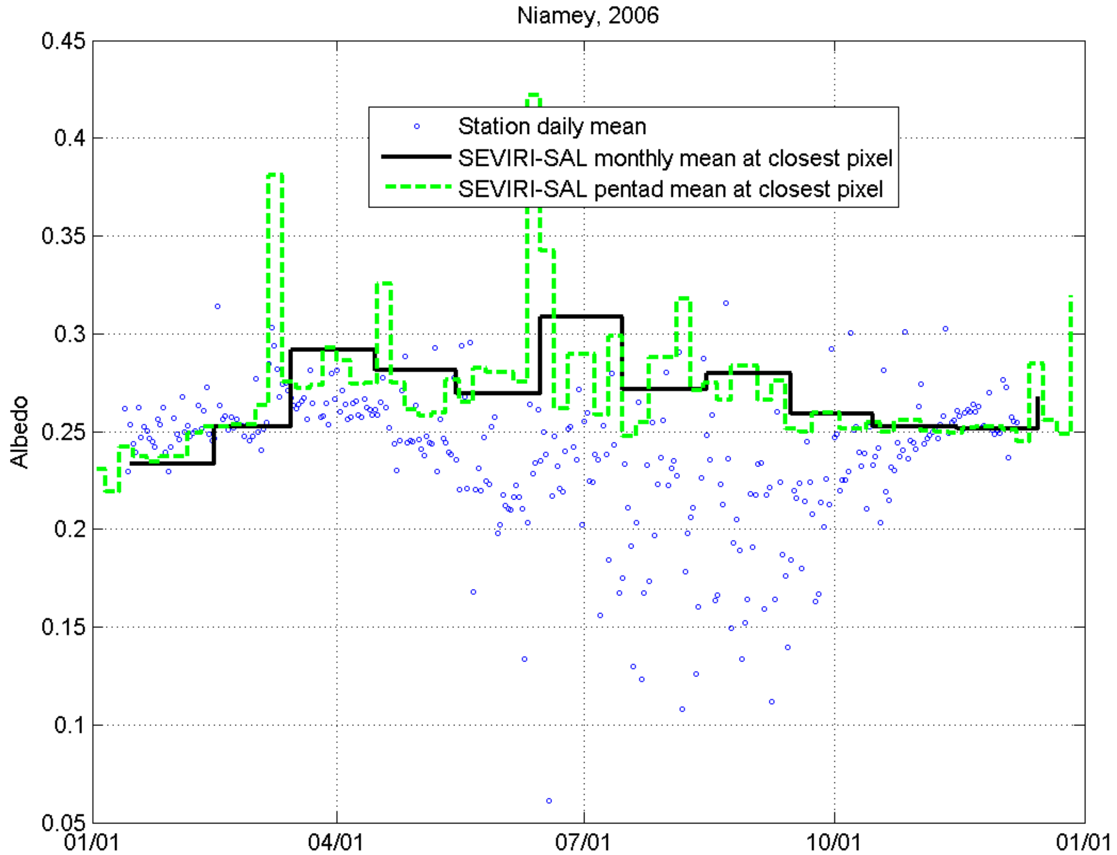

Figure 7: CLAAS-SAL and in situ albedo at Niamey. Blue circles indicate instantaneous CLAAS-SAL retrievals, and the black and green (dashed) lines indicate the CLAAS-SAL monthly and pentad mean albedos.

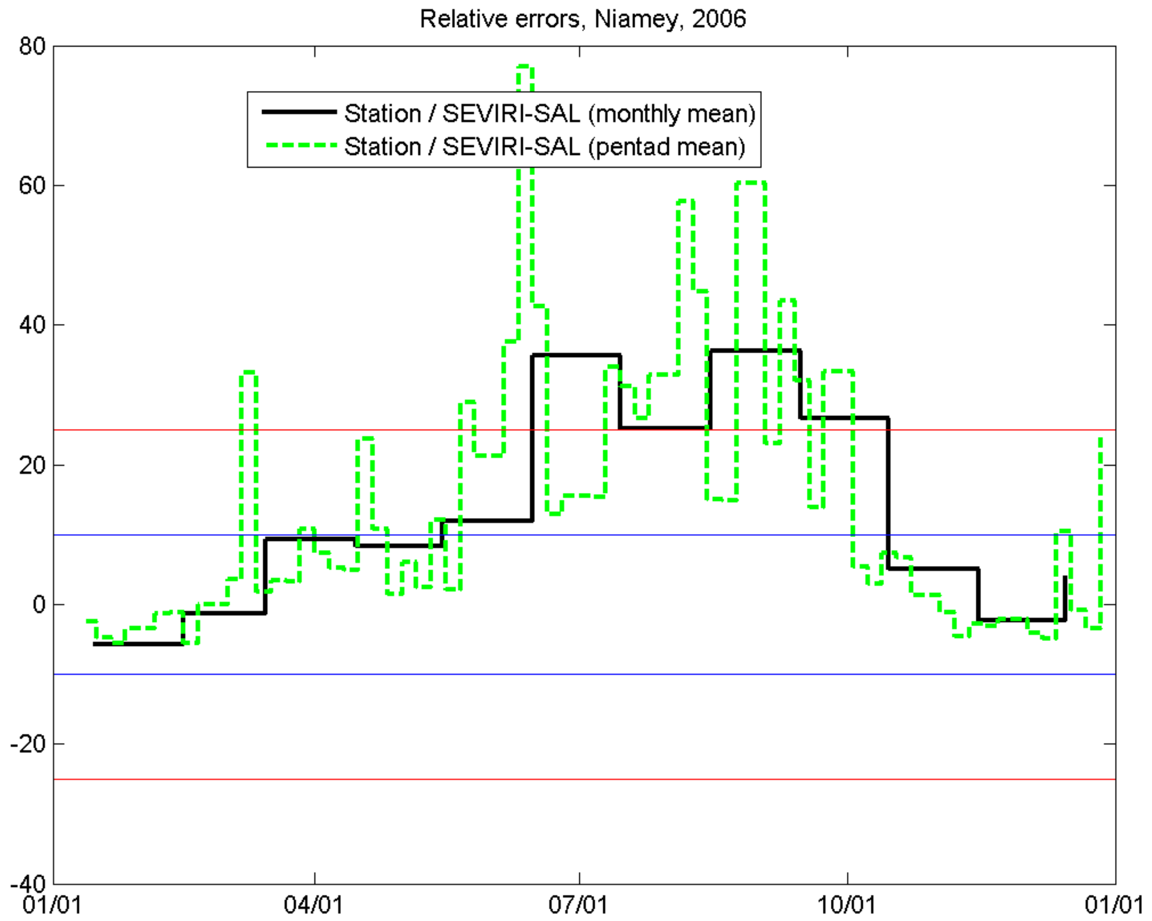

Figure 8: CLAAS-SAL relative retrieval error over Niamey. The black and green (dashed) lines indicate the retrieval error of the monthly and pentad means. Red dashed line shows 25% and the blue dashed line 10% relative error levels.

Table 7: CLAAS-SAL product quality indicators at the monthly mean level over Niamey.

Dataset / period	RMSE	Mean rel. retrieval error [%]	Mean abs. retrieval error [%]	Notes
Instantaneous	-	-		not recorded at Niamey
Monthly means	0.041	12.75	14.32	N=12
DJF	0.010	-1.02	3.69	N=3
MAM	0.025	9.87	9.87	N=3
JJA	0.071	32.36	32.36	N=3
SON	0.032	9.81	11.34	N=3

Table 8: CLAAS-SAL product quality indicators at the pentad mean level over Niamey.

Dataset / period	RMSE	Mean rel. error [%]	Mean abs. retrieval error [%]	Notes
Pentad means	0.050	13.74	15.41	N=62
DJF	0.021	-2.44	6.25	N=18
MAM	0.036	10.10	10.10	N=18
JJA	0.079	32.32	32.32	N=18
SON	0.038	12.15	13.70	N=18

6. Summary of land-based validation site results

The validation results for all land-based sites are summarized in Table 9. Only monthly mean validation results are shown as the pentad mean results are highly similar.

Table 9: Validation results summary for monthly means over all land-based sites.

Site	RMSE	Mean relative retrieval error [%]	Mean absolute retrieval error [%]
Payerne, Switzerland	0.031	-3.08	8.94
Lindenberg, Germany	0.067	-2.66	9.68
ARM Mobile Facility Niamey	0.041	12.75	14.32

7. Comparison against MODIS products

The previous validation results show the CLAAS-SAL product accuracy against ground truth over small scales. It is, however, equally valuable to know how CLAAS-SAL compares to other satellite-based albedo products.

We have carried out a comparison to the MCD43C3 black-sky shortwave albedo product from MODIS. The chosen study year was 2009. The MODIS product was cropped to fit the S1-SAL data extent (-90 -> 90 N, -90 -> 90 E). Further, any grid cells where either product did not have a valid albedo value were discarded from the analysis. We did not weigh the albedo products for irradiance or area. To fit CLAAS-SAL pentads to the 16-day MODIS products in time, we averaged all CLAAS-SAL pentads within the MODIS coverage period, plus minus one day to make the temporal matching better.

An example comparison (starting on DOY 137 of 2009) is shown in Figure 9 - Figure 11. CLAAS-SAL retrievals are consistently higher over the covered area of the globe. Figure 12 shows the mean albedo of land/snow covered surfaces throughout 2009 for both products, and their relative difference. CLAAS-SAL is, again, consistently about 20% higher. As the TOA reflectances in CLARA-S1 dataset have been recalibrated to match MODIS, we can hypothesize that the atmospheric correction and BRDF effects are the main source of difference (as the spectral coverages of the products are nearly identical).

The example products and differences shown here are representative of the (NH) summer 2009 timeframe. During the winter period, differences between MODIS and CLAAS-SAL are larger both in Europe and Sub-Saharan Africa. An interesting feature of the comparison is that the albedo of the Sahara region is highly similar in both satellite products despite the differences in atmospheric correction and BRDF models.

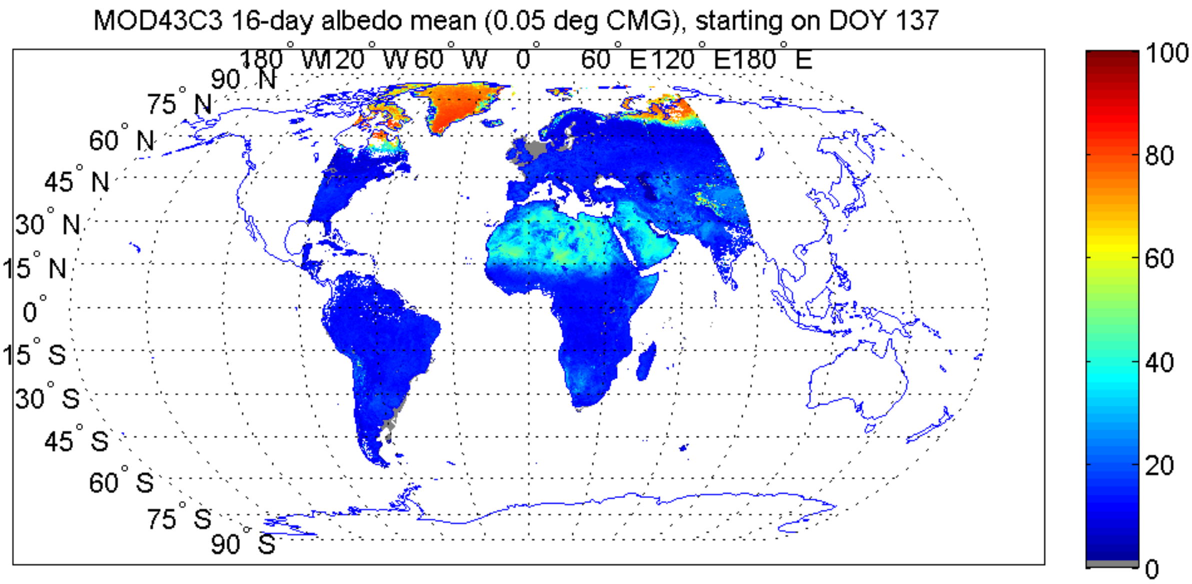

Figure 9: MCD43C3 16-day BSA shortwave albedo product starting from DOY 137 of 2009. Product has been cropped to CLAAS-SAL data coverage area; actual retrievable S1-SAL area is smaller (see next figure).

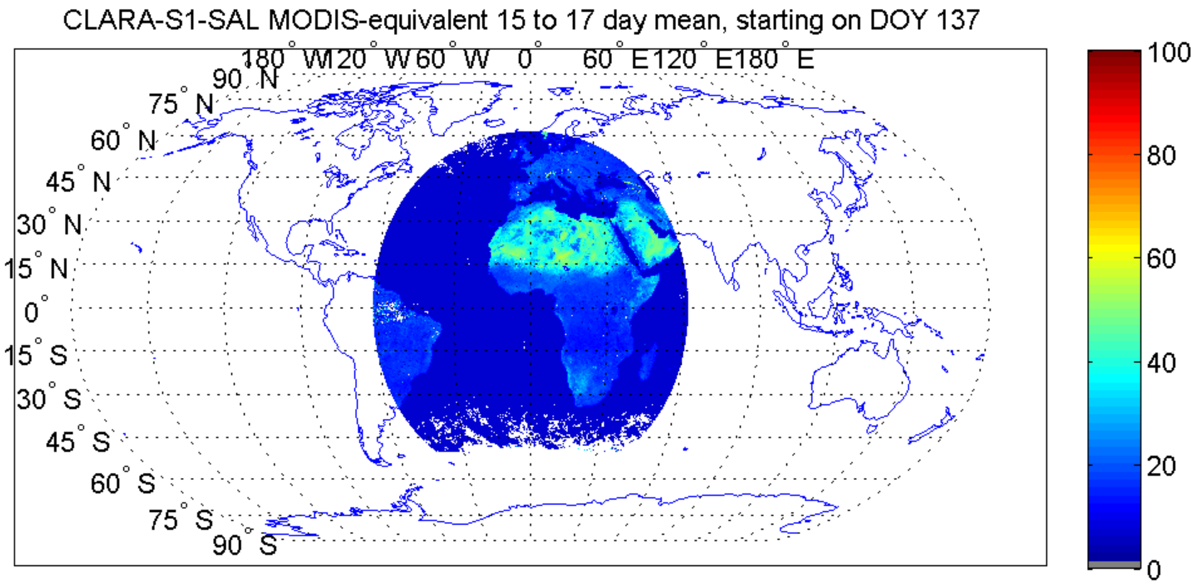

Figure 10: A composite of three CLAAS-SAL pentads fitting within (±1 day) the 16-day MCD43C3 period starting on DOY 137 of 2009.

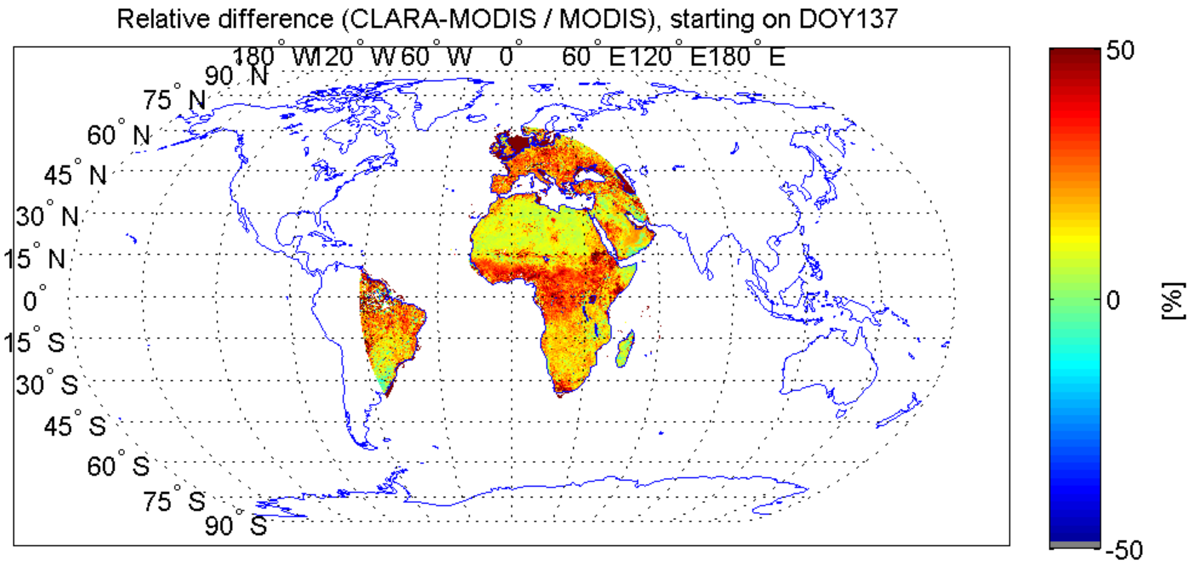

Figure 11: Relative difference (in %) between CLAAS-SAL and MCD43C3 over the 16-day MODIS product period starting on DOY 137 of 2009.

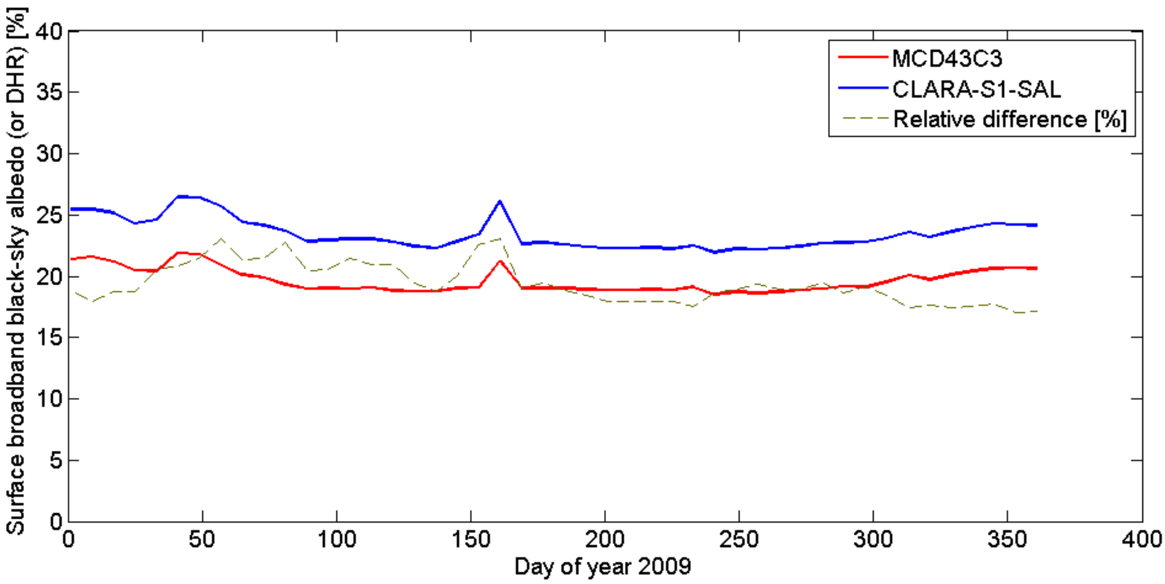

Figure 12:Land/snow surface global black-sky albedo mean for 2009 from the MCD43C3 and CLAAS-SAL pentad composites. Red and blue lines indicate MODIS and CLAAS-SAL albedo, respectively, and the dashed brown line shows the relative difference (in % using left y-axis) between the products. The albedo has not been weighted for irradiance or area.

8. Product Stability

We assess the temporal stability of CLAAS-SAL over regions known to exhibit stable albedo over long time-periods. To do this, we have chosen two study sites; one over the Libyan desert (Sahara testsite) and another over the Schwarzwald Forest in central Germany. The study sites and regions of CLAAS-SAL averaging were shown in Figure 2.

The stability results of the Sahara site are shown in Figure 13. The analysed area comprised of 5 x 5 SAL pixels to remove any sporadic cloud misclassification effects. The albedo over the site is fairly stable over the 8-year dataset period, although an annual cycle is visible. This cycle is most likely related to annual changes in AOD content in the atmosphere over the site, as well as some variation from seasonally varying Sun Zenith Angles. The maximum deviation of the monthly mean S1-SAL products from the 8-year mean albedo is **12.42%** (relative).

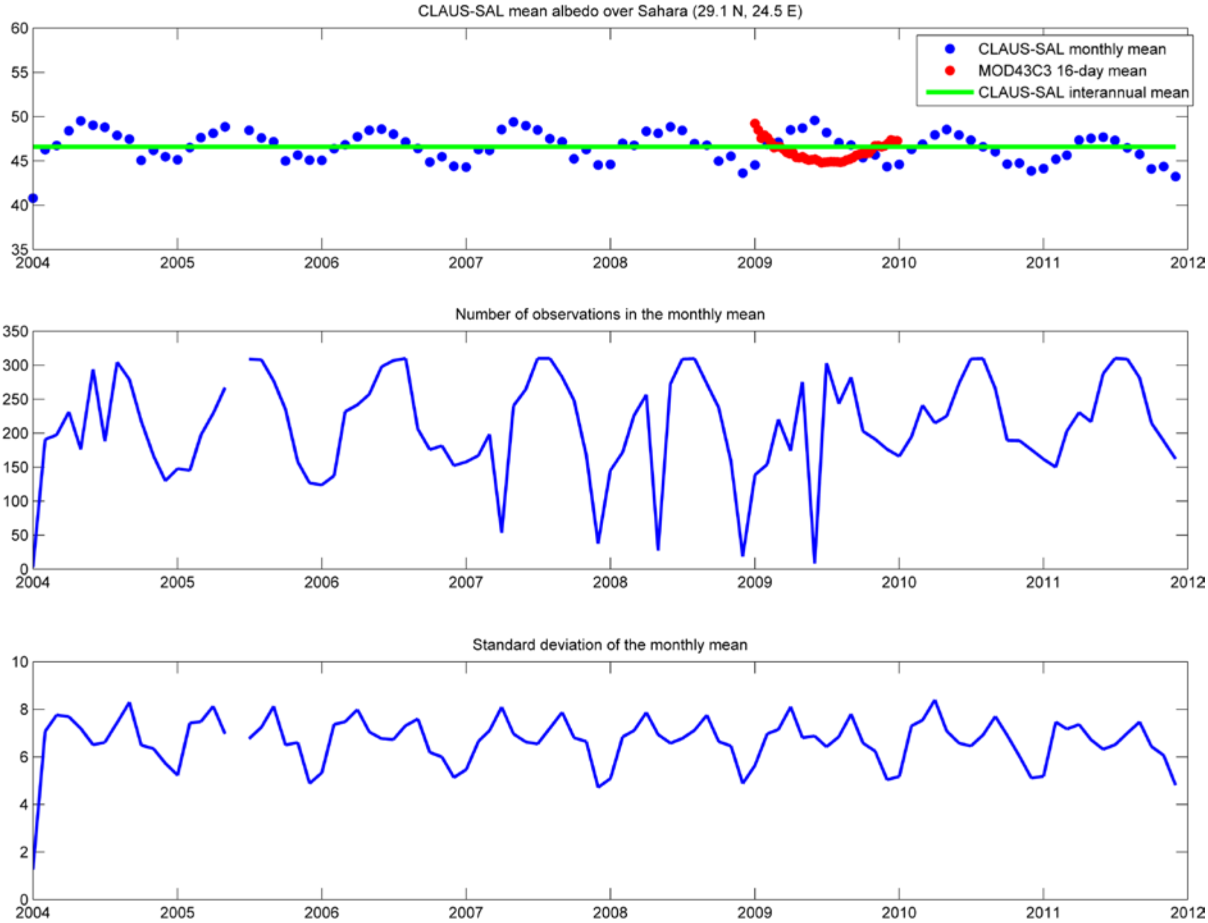

Figure 13: Stability analysis of the Sahara region. Monthly mean S1-SAL products analysed.Upper subplot: SW BB black-sky albedo of the Sahara test site. MODIS MCD43C3 data included from 2009 for comparison. Middle subplot: Mean number of observationsin the testsite mean albedo. Lower subplot: Mean standard deviation [percentage units of albedo] of CLAAS-SAL over the Sahara test site.

The Schwarzwald forest area contains considerable topographical features and experiences occasional snowfall. Figure 14 shows the results from investigating the single CLAAS-SAL grid cell (0.05 deg) closest to 48N, 8E between 2004-2011. The snow-free season time series is quite stable over the 8-year period. The winter/spring snow-cover is variable, as also seen in the large standard deviation of the monthly mean during most November-March periods.

To gain some perspective on CLAAS-SAL stability over Schwarzwald, we investigated the stability of the snow-free May-September period. The 8-year mean albedo of this period was 0.160 (note: scale in Figure 14 is 0-100%). The largest deviation from this value over the period was 0.014, which is **8.75%** in relative terms. Since the Schwarzwald site experiences less AOD loading (and variability) compared to the Sahara site, we consider the Schwarzwald summer-time stability to be more representative of the CLAAS-SAL algorithm itself; the larger deviations at the Sahara site are attributable to AOD variation, which can be remedied with an algorithm input update in the next edition (CLARA-S2-SAL).

Finally, it should be remarked that as the dataset covers 8 years in time, the stability indicators should be considered only as a first estimate of the decadal stability of this dataset. On the other hand, we note with satisfaction that the MSG satellite change in 2007 went smoothly in terms of dataset stability.

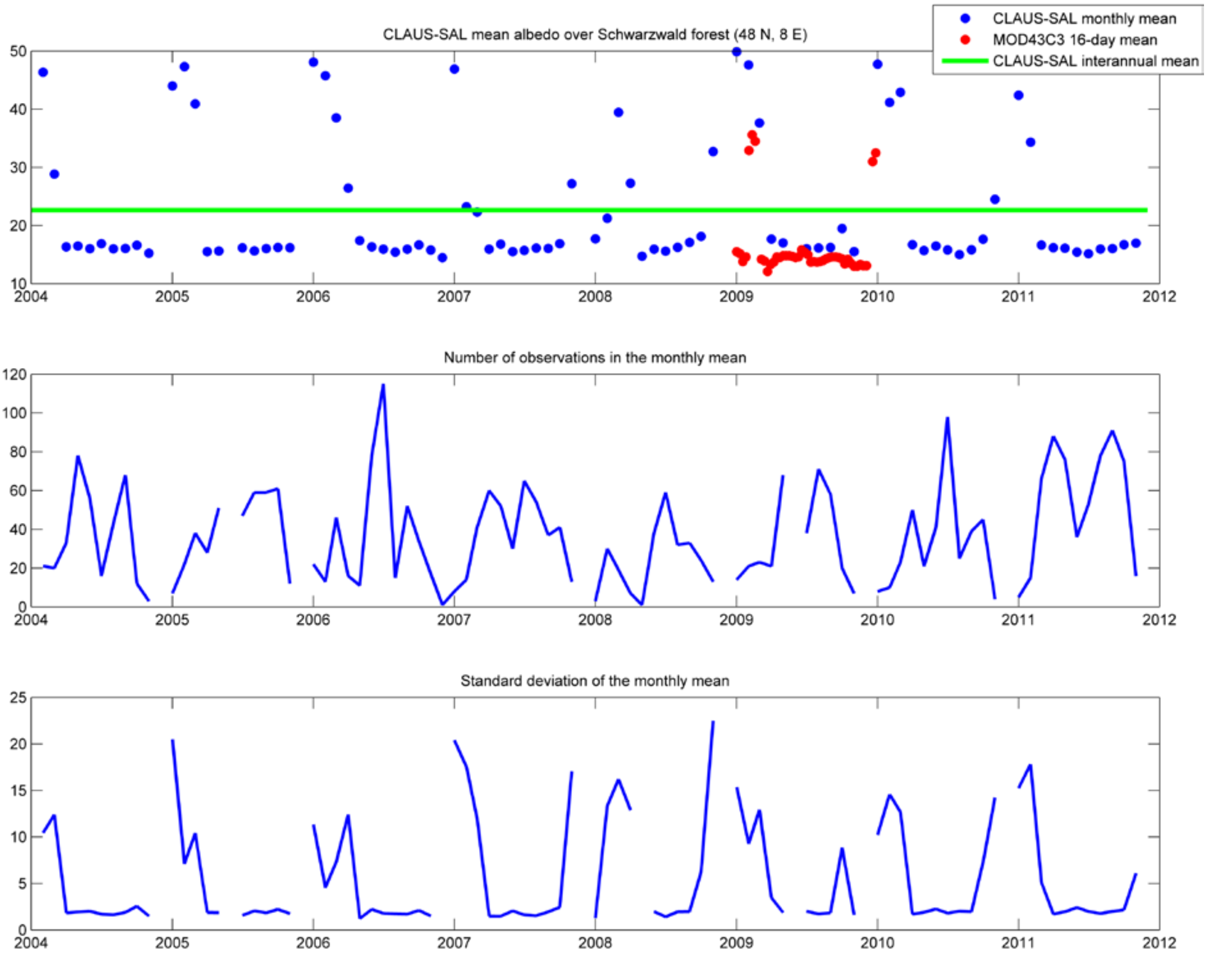

Figure 14:CLAAS-SAL stability over Schwarzwald forest, Germany (48 N, 8 E). Monthly means.Figure content as in Figure 13.

9. Conclusions

This report has presented the findings of the validation study on the CLAAS-SAL dataset. The CLAAS-SAL products have been validated against in situ data from the surface albedo observation sites in Europe and Africa. Validation took place between 2004-2011 at Lindenberg, between 2004-2009 at Payerne, and during 2006 at Niamey. The dataset temporal stability has been assessed at two locations, one in the Libyan desert and one in central Germany. The products were also compared to black-sky shortwave albedo products from the MODIS (MCD43C3) sensors.

The validation and temporal stability analysis results show that:

a) CLAAS-SAL is stable over regions with light-to-moderate aerosol loading (e.g. Schwarzwald) over the dataset coverage period.

b) CLAAS-SAL mostly tracks the in situ albedo within the S1-SAL accuracy requirement (25% relative). Areas with high and variable aerosol loading have larger retrieval errors (e.g. the Niamey validation site during midsummer). Drastic albedo-changing events (mainly snowfall and –melt) combined with the problem of heterogeneity in land/snow cover at the S1-SAL resolution can impair comparability; the issue, however, is not specific to the S1-SAL algorithm but to satellite albedo retrievals in general.

c) CLAAS-SAL pentad mean products are more sensitive to retrieval errors than the monthly means, as can be expected.

The comparison with MCD43C3 16-day mean albedo products showed that CLAAS-SAL generally produces higher albedo over vegetation (by 10-20% relative). The same is true for snow albedo, although we note that the SAL snow albedo retrieval algorithm is designed for polar orbiter use; application to geostationary SEVIRI data is not an optimal solution. By studying the geographical distribution of MODIS-SAL differences, it becomes clear that the constant AOD used in SAL atmospheric correction processing is the main source of differences. Indeed, considering that the SEVIRI solar channel reflectances have been recalibrated to MODIS standard prior to SAL processing, we may discount instrument-to-instrument calibration differences as a major source of discrepancy.

10. Acknowledgments

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12. Abbreviations

AOD	Aerosol Optical Depth
APP-X	AVHRR Polar Pathfinder Extended
AVHRR	Advanced Very High Resolution Radiometer (NOAA)
BB	Broadband
BRDF	Bidirectional Reflectance Distribution Function
BSRN	Baseline Surface Radiation Network
CERES	Clouds and the Earth's Radiant Energy System
CDOP	Continuous Development and Operations Phase
CLAAS-SAL	CM SAF cLouds, Albedo and Radiation – Surface Albedo product
CM SAF	Satellite Application Facility on Climate Monitoring
DEM	Digital Elevation Model
DWD	Deutscher Wetterdienst
ECMWF	European Center for Medium-Range Weather Forecasts
ECV	Essential Climate Variable
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EPS	Enhanced Polar System
FMI	Finnish Meteorological Institute
GC-Net	Greenland Climate Network
GCOS	Global Climate Observing System
KNMI	Royal Netherlands Meteorological Institute
LUC	Land Use Classification
LUT	Look-Up Table
MODIS	Moderate Resolution Imaging Spectroradiometer
NH	Northern Hemisphere
NOAA	National Oceanic and Atmospheric Administration
NTB (C)	Narrow-to-Broadband (Conversion)
PPS	Polar Platform System
RMIB	Royal Meteorological Institute of Belgium
SAF	Satellite Application Facility
SMAC	Simplified method for the atmospheric correction of satellite measurements in the solar spectrum

SMHI	Swedish Meteorological and Hydrological Institute
SZA	Sun Zenith Angle
TOA	Top of Atmosphere
USGS	United States Geological Survey
VZA	Viewing Zenith Angle