

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

This discussion paper is/has been under review for the journal Atmospheric Measurement Techniques (AMT). Please refer to the corresponding final paper in AMT if available.

MERIS albedo climatology for FRESCO+ O₂ A-band cloud retrieval

C. Popp¹, P. Wang², D. Brunner¹, P. Stammes², Y. Zhou¹, and M. Grzegorski³

¹Empa, Swiss Federal Laboratories for Materials Science and Technology,
Dübendorf, Switzerland

²Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands

³Max-Planck-Institute for Chemistry, Mainz, Germany

Received: 23 September 2010 – Accepted: 25 October 2010 – Published: 27 October 2010

Correspondence to: C. Popp (christoph.popp@empa.ch)

Published by Copernicus Publications on behalf of the European Geosciences Union.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Abstract

A new global albedo climatology for Oxygen A-band cloud retrievals is presented. The climatology is based on MEdium Resolution Imaging Spectrometer (MERIS) Albedomap data and its favourable impact on the derivation of cloud fraction is demonstrated for the FRESCO+ (Fast Retrieval Scheme for Clouds from the Oxygen A-band) algorithm. To date, a relatively coarse resolution ($1^\circ \times 1^\circ$) surface reflectance dataset from GOME (Global Ozone Monitoring Experiment) Lambert-equivalent reflectivity (LER) is used in FRESCO+. The GOME LER climatology does not account for the usually higher spatial resolution of UV/VIS instruments designed for trace gas remote sensing which introduces several artefacts, e.g. in regions with sharp spectral contrasts like coastlines or over bright surface targets. Therefore, MERIS black-sky albedo (BSA) data from the period October 2002 to October 2006 were aggregated to a grid of $0.25^\circ \times 0.25^\circ$ for each month of the year and for different spectral channels. In contrary to other available surface reflectivity datasets, MERIS includes channels at 754 nm and 775 nm which are located close to the spectral windows required for O₂ A-band cloud retrievals.

The MERIS BSA in the near infrared compares well to Moderate Resolution Imaging Spectroradiometer (MODIS) derived BSA with an average difference lower than 1% and a correlation coefficient of 0.98. However, when relating MERIS BSA to GOME LER a distinctly lower correlation (0.80) and enhanced scatter is found. Effective cloud fractions from two exemplary months (January and July 2006) of Scanning Imaging Absorption Spectrometer for Atmospheric Chartography (SCIAMACHY) data were subsequently derived with FRESCO+ and compared to those from the Heidelberg Iterative Cloud Retrieval Utilities (HICRU) algorithm. The MERIS climatology generally improves FRESCO+ effective cloud fractions. In particular small cloud fractions are in better agreement with HICRU. This is of importance for atmospheric trace gas retrieval which relies on accurate cloud information at small cloud fractions. In addition, overestimates along coastlines and underestimates in the Intertropical Convergence Zone introduced

AMTD

3, 4603–4644, 2010

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



by the GOME LER were eliminated. While effective cloud fractions over the Saharan desert and the Arabian peninsula are successfully reduced in January, they are still too high in July relative to HICRU due to FRESCO+'s large sensitivity to albedo inaccuracies of highly reflecting targets and inappropriate aerosol information which hampers an accurate albedo retrieval. Apart from FRESCO+, the new MERIS albedo data base is applicable to any cloud retrieval algorithms using the O₂ A-band or the O₂-O₂ absorption band around 477 nm. Moreover, the by-product of BSA at 442 nm can be used in NO₂ remote sensing and the BSA at 620 nm, 665 nm, and 681 nm could be integrated in current H₂O retrievals.

1 Introduction

Accurate cloud information is an important prerequisite for the retrieval of atmospheric trace gases from spaceborne UV/VIS sensors. Errors in the estimated cloud fraction and cloud height (pressure) result in erroneous air mass factors and thus lead to inaccuracies in the vertical column densities of the retrieved trace gas. For example, Boersma et al. (2004) estimated in their tropospheric NO₂ error analysis average uncertainties in the tropospheric air mass factor as large as 30% due to cloud fraction and up to 10% due to cloud top pressure inaccuracies. In addition, the majority of the UV/VIS instruments have a rather coarse spatial resolution which increases the probability of cloud contamination in the sensor's field of view (e.g., Krijger et al., 2007). Several algorithms for the retrieval of cloud fraction and cloud pressure from UV/VIS sensors have been developed, depending on the instrument's spectral characteristic. Some take advantage of the oxygen absorption in the O₂ A-band around 760 nm (e.g. Koelemeijer et al., 2001; Wang et al., 2008; Kokhanovsky et al., 2006), absorption in the O₂-O₂ band around 477 nm (e.g. Acarreta et al., 2004), O₂ absorption in several bands (Wagner et al., 2008), Raman scattering (Vasilkov et al., 2008), or of a combination of measurements from the Polarisation Monitoring Devices (PMD) with measurements either in the O₂- γ -band (Grzegorski et al., 2006) or in the O₂ A-band (Loyola et al.,

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



2007). Since O₂ is a well-mixed gas, O₂ A-band retrieval algorithms utilize the varying depth of the oxygen absorption as a function of the oxygen amount above the cloud (Koelemeijer et al., 2001).

In ESA's TEMIS (Tropospheric Emission Monitoring Internet Service) project, the FRESCO+ (Fast Retrieval Scheme for Clouds from the Oxygen A-band) cloud retrieval is applied to SCIAMACHY (SCanning Imaging Absorption SpectroMeter for Atmospheric ChartographY) and Global Ozone Monitoring Experiment (GOME(-2)) data to derive effective cloud fraction and cloud pressure for each pixel. FRESCO+ (Wang et al., 2008) uses measured top-of-atmosphere (TOA) reflectance in three wavelength windows inside and outside of the O₂ A-band (at 758–759 nm, 760–761 nm, and 765–766 nm). Effective cloud fraction and cloud pressure are retrieved by minimizing the difference between TOA reflectance from radiative transfer calculations and the measured TOA reflectance. With regard to the radiative transfer simulations, FRESCO+ relies on a surface reflectance climatology based on GOME Lambert-equivalent reflectivity (LER) acquired between June 1995 and December 2000 (Koelemeijer et al., 2003). However, the relatively coarse resolution (1° × 1°) of the GOME LER data base often inadequately represents surface reflectivity in the instantaneous field of view of recent UV/VIS instruments (e.g. ground pixel size of 30 × 60 km for SCIAMACHY) thereby introducing several artefacts in cloud and trace gas retrievals. For example in regions with strong spatial gradients of reflectance like coastlines (cf. Fig. 1), the surface albedo over land is often underestimated which results in an overestimation of the effective cloud fraction. In addition, land use changes during the past decade potentially introduce further inaccuracies in the cloud parameter retrieval.

For these reasons, we test the substitution of the GOME LER climatology in FRESCO+ with a land surface albedo climatology compiled for every month from MEdium Resolution Imaging Spectrometer (MERIS) Albedomap data (Muller, 2008) covering the period October 2002 to October 2006. Contrary to other available BRDF/albedo products, e.g. from the Moderate Resolution Imaging Spectroradiometer (MODIS, Schaaf et al., 2002), the MERIS dataset provides albedo values at 754 nm

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[⏪](#)[⏩](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

and 775 nm located close to both sides of the O₂ A-band as required by FRESCO+. Further, the increased spatial resolution of the MERIS product in comparison to the GOME LER data base (0.05° × 0.05°, herein aggregated to 0.25° × 0.25°) allows to better account for the typical pixel size of UV/VIS sensors. The aim of this study is to describe and assess (i) the compilation and quality of the MERIS albedo climatology, (ii) the differences to the GOME LER climatology, and (iii) to demonstrate the enhancements in the FRESCO+ O₂ A-band cloud retrieval after integration of the MERIS albedo climatology based on SCIAMACHY data.

2 FRESCO+

The basic FRESCO algorithm is described in detail in Koelemeijer et al. (2001) and the updated FRESCO+ in Wang et al. (2008). Cloud retrieval in the O₂ A-band takes advantage of the larger reflectance of (subpixel) clouds in the continuum window (758–759 nm) as well as the varying depth of the oxygen absorption at 760 nm and 765 nm as a function of cloud height and cloud optical thickness. Effective cloud fraction and cloud pressure are inverted by minimizing the difference between radiative transfer simulations of TOA reflectance and the measured TOA reflectance by applying the Levenberg-Marquart nonlinear least squares method. Following the independent pixel assumption, the (simulated) TOA reflectance can be expressed as the sum of terms containing the reflectance from the cloudy part and from the cloud-free part of the pixel:

$$R_{\text{sim}} = c A_c T_c + (1 - c) A_s T_s + c R_c + (1 - c) R_s \quad (1)$$

where subscript c indicates cloud related and subscript s surface related parameters. Hence, A_c and A_s are the cloud and surface albedo, c is the effective cloud fraction, T_s and T_c the direct transmissions along the photon path (from the sun to surface or cloud and back to TOA), and R_c and R_s the single Rayleigh scattering reflectance including O₂ absorption between the cloud (surface) and TOA. The transmissions T_c and T_s depend on the solar zenith angle and the viewing zenith angle and include O₂

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



absorption and Rayleigh extinction. With the exception of c , all parameters in Eq. (1) are wavelength dependent. Cloud pressure is a function of the depth of the O₂ A-band. The radiative transfer calculations include an assumed cloud albedo of 0.8, a mid-latitude summer atmosphere profile (Anderson et al., 1986), surface height from the GTOPO30 digital elevation model (from the US Geological Survey's EROS data center), surface albedo from a climatology based on GOME measurements, and TOMS (Total Ozone Mapping Spectrometer) surface albedo (Herman and Celarier, 1997) to estimate snow or ice covered areas. From a computational perspective, a transmission data base is pre-calculated by line-by-line radiative transfer calculations, convoluted with the slit function of SCIAMACHY (Wang et al., 2008).

The FRESCO algorithm/software has undergone several improvements and different validations. In its first version (Koelemeijer et al., 2001), the surface albedo of ocean was assumed to be constant at 0.02 and the surface albedo of land was estimated from minimum reflectivity data from two months of GOME observations on a grid of 2.5° × 2.5° resolution. Subsequently, Koelemeijer et al. (2003) compiled a climatology of Lambert-equivalent reflectivity (LER) based on several years of GOME data on a monthly basis and a spatial resolution of 1° × 1°. The spectrum corresponding to the minimum LER at 670 nm per month and grid cell is stored in the data base. The surface LER used in FRESCO are at 758 nm and 772 nm. Fournier et al. (2006) found an overestimation of effective cloud fraction over deserts which they attributed to (absorbing) desert dust aerosols and corrected this effect by increasing the monthly surface albedo by (empirically found) 20% at desert locations with a monthly six-year average of the Absorbing Aerosol Index (AAI) from GOME larger than one. Finally, Wang et al. (2008) added single Rayleigh scattering (last two terms in Eq. 1) in the radiative transfer calculations thereby mainly improving the estimation of cloud pressure for less cloudy pixels which is of special interest for trace gas retrieval in the troposphere.

FRESCO+ retrieves an effective cloud fraction which describes the fraction of an optically thick Lambertian cloud with a fixed albedo of 0.8 that results in the same TOA radiance as the real cloud. Thus, the effective cloud fraction is a radiometric

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



equivalent cloud fraction. This concept has been proven useful for trace gas remote sensing applications (Koelemeijer et al., 2001; Stammes et al., 2008) and estimated errors introduced to trace gas retrievals are usually quite small when compared to scattering cloud models (Stammes et al., 2008). However, it should be emphasized that the effective cloud fraction is not directly comparable to (and usually smaller than) the geometric cloud fraction like e.g. reported by synoptic observations of weather services or derived applying other algorithms (e.g. Kokhanovsky et al., 2009). The retrieval of cloud information is seriously hampered over snow contaminated surfaces because it is difficult to separate the measured and the cloud's radiometric signal over surfaces which exhibit a similar reflection as the cloud itself (e.g., Tuinder et al., 2004). It further follows from Eq. (1) that the effective cloud fraction becomes highly sensitive to errors in the surface albedo when the surface albedo approaches the cloud albedo (Koelemeijer et al., 2001). Therefore, over snow/ice no cloud fraction is retrieved but a scene albedo and scene pressure are retrieved.

3 MERIS albedo data base

3.1 Albedomap data

The European Space Administration (ESA) initiated the Albedomap project with the aim to create a global land surface albedo dataset from MERIS measurements. The resulting white-sky and black-sky albedo data are publicly available from <http://www.brockmann-consult.de/albedomap/browse/index.html> created for periods of 16 days or one month, respectively. Black-sky albedo (BSA) is the ratio of the upwelling to downwelling direct radiative flux (often also called the directional hemispherical reflectance), white-sky albedo is the ratio of the upwelling to downwelling (isotropic) diffuse flux (bihemispheric reflectance). Global surface albedo maps are available for the period July 2002 to November 2006 on a grid of $0.05^\circ \times 0.05^\circ$. However, due to quality issues in the August and September 2002 data, we compile the climatology based on

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page	
Abstract	Introduction
Conclusions	References
Tables	Figures
◀	▶
◀	▶
Back	Close
Full Screen / Esc	
Printer-friendly Version	
Interactive Discussion	

data from October 2002 onward. The albedo maps are spatially complete with the exception of regions affected by polar darkness and some patches in adjacent regions between approx. 55° N and 60° N in Siberia and Canada for the months of October, November, and December. The cause of the latter artefact is currently not known.

5 White- and black-sky albedos are available for 13 out of 15 spectral bands of MERIS between 412 nm and 885 nm¹. The MERIS channels at 754 nm and 775 nm are located spectrally close to both sides of the O₂ A-band and are therefore of special interest in this study. A detailed description of the derivation of surface albedo from MERIS data can be found in Muller (2008). In brief, top-of-atmosphere MERIS Level2 reflectance is first cloud-screened and corrected for aerosol extinction (Schroeder et al., 2005) providing the MERIS Level 2 SDR (surface directional reflectance). The cloud detection is based on simulated radiances representing the natural variability of cloud and surface spectral properties which train an artificial neural network that converts the MERIS measurements into likelihood of cloudiness (Preusker et al., 2008). A post-processing is subsequently applied including several spectral and temporal tests and cloud edge detection in order to improve cloud shadow detection, discrimination between cloud and snow/ice and the detection of thin clouds. The aerosol correction uses aerosol optical depth and Angstrom coefficient derived from the daily MODIS aerosol product (Kaufman and Tanré, 1998) or from the the Global Aerosol Data Set (GADS) climatology (Koepke et al., 1997). The daily SDR of a 16-day period are subsequently averaged to the resolution of 0.05° in accordance to the MODIS Climate Modelling Grid BRDF (bi-directional reflectance distribution function) product (MOD43C, Schaaf et al., 2002). A magnitude inversion technique is then applied to the shape of the MODIS BRDF using the MERIS SDR. Black-sky and white-sky albedo are finally obtained by integrating the corresponding BRDF over the hemisphere, in case of the black-sky albedo for the mean solar zenith angle of the corresponding 16-days periods (Muller, 2008). In

¹i.e. 412 nm (bandwidth 10 nm), 442 nm (10 nm), 490 nm (10 nm), 510 nm (10 nm), 560 nm (10 nm), 620 nm (10 nm), 665 nm (10 nm), 681 nm (7.5 nm), 709 nm (10 nm), 754 nm (7.5 nm), 775 nm (15 nm), 865 nm (20 nm), 885 nm (10 nm)



addition, a monthly product is generated by averaging the 16-day data weighted by the number of days falling in the specific month. It is emphasized that the MERIS albedo data depends on the quality of the MODIS BRDF parameters. These parameters could be originating from a full inversion or in case of poor sampling from a predetermined global and season-dependent data base of BRDF parameters characteristic for different land cover types (Schaaf et al., 2002). The Albedomap dataset provides albedo values for land surfaces and shallow water areas but not for deep ocean pixels.

3.2 Compilation of the MERIS BSA climatology

Using the Albedomap data we compiled a monthly climatology by averaging over the period 2002–2006. Black-sky albedo is chosen as the reflectance quantity of interest for reasons explained in Sect. 4.1. The processing is straightforward and the following steps are performed for each spectral channel:

1. All valid BSA pixels for a particular month of the year from the $0.05^\circ \times 0.05^\circ$ data base are collected in boxes of $0.25^\circ \times 0.25^\circ$. The MODIS monthly snow product MOD10CM (Hall et al., 2002) on a grid of 0.05° resolution is used to reject snow contaminated pixels. If a box contains less than 25 out of 100 (25 pixels \times 4 years) possible valid and snow/ice-free pixels it is regarded unreliable because of e.g. too much snow coverage or corrupted data. In this case the grid cell is left empty and filled later.
2. If the MODIS snow product indicates that more than 25% of the valid BSA pixels are snow-free, the median of all snow-free black-sky albedo values is stored in the corresponding grid cell. We choose the median BSA to reduce the impact of possible outliers like undetected snow.
3. If the MODIS snow product indicates that more than 75% of all valid pixels have a snow fraction larger than 0.75, the median BSA of all these snow covered pixels and the corresponding snow fraction are stored.

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

4. For grid cells with more than 25 valid pixels but not filled during steps 2 and 3, the median and the corresponding snow fraction are stored and these grid cells are flagged as (subgrid) snow contaminated.
5. Empty grid cells (e.g. due to polar darkness) are filled with the value from the closest month and a corresponding flag is set.
6. Water pixels are finally filled (or replaced in case of shallow water near the shores) by the LER from the GOME data base and a corresponding flag is set.

In contrast to climatologies built from lower level data (e.g., Kleipool et al., 2008; Koelemeijer et al., 2003) we do not have to deal with cloud masking because the data base is already sufficiently cloud screened (Preusker et al., 2008). Therefore, the median is applied in the second step to minimize the influence of potential outliers, e.g. snow. Step 4 leads to subgrid snow contaminated pixels in the dataset which are flagged but might be used for some applications. Step 5 is mainly performed to obtain a spatially complete dataset. A majority of missing pixels can be assigned to unfavourable illumination conditions, e.g. during winter at high latitudes.

Global RGB composites of the resulting climatology are presented in Fig. 2 for the months of January and July. An artificial blue color is assigned to water pixels. The differences between winter and summer are well depicted. Snow coverage in the northern hemisphere is widespread in January and characterized by high reflectivity in the three bands (R: 665 nm, G: 560 nm, B: 490 nm) used to build the RGB. In addition, the greening of vegetation e.g. in North America or the Sahel as well as some changes toward arid conditions during summer, e.g. in Spain, are well detectable.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

4 Results and discussion

4.1 Comparison to GOME LER and MODIS BSA

We compare our MERIS black-sky albedo dataset with two existing albedo climatologies, namely the spatially complete MODIS black-sky (Moody et al., 2008) and the GOME LER (Koelemeijer et al., 2003) datasets. It should be noted that black-sky albedo is not the same measure as the Lambert-equivalent reflectivity. BSA is the integral of the BRDF over the entire hemisphere whereas the LER is derived from a much smaller range of viewing angles of the satellite's observation geometry (e.g., Kleipool et al., 2008). Further, the MERIS BSA (overpass at 10:30 LT – local time) are reported for the mean solar zenith angle of the 16-day periods which does not necessarily have to accord to the solar zenith angles of GOME data acquisition (overpass at 10:00 LT) that was used for the GOME LER. Finally, diffuse illumination is disregarded in the BSA whereas in reality some part of the illumination is usually diffuse (blue-sky albedo). However, we justify the use of black-sky albedo for FRESCO+ because (i) in FRESCO+, the albedo climatology is exclusively used to perform the radiative transfer calculations for the clear-sky part of the pixel (cf. Eq. 1); (ii) in clear-sky cases (only aerosol and Rayleigh scattering) diffuse irradiance around 760 nm is usually small compared to the direct irradiance; (iii) the black-sky albedo is generally very similar to the blue-sky albedo for moderate solar zenith angles (0° – 50° , Liu et al., 2009) because the diffuse component decreases with decreasing solar zenith angle; and (iv) the “actual” (blue-sky) albedo is difficult to calculate because accurate knowledge about the atmospheric optical depth is required which is highly variable in space and time. Oleson et al. (2003) reported differences of not more than 2% between BSA and blue-sky albedo and less than 2.3% between BSA and WSA for different zonal averages.

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



4.1.1 GOME LER climatology

The GOME LER climatology is described in detail in Koelemeijer et al. (2003). In summary, the climatology provides LER in eleven spectral bands between 335 nm and 772 nm suitable for a wide range of applications (e.g. retrieval of trace gases or aerosols) derived from GOME measured spectra with a spatial resolution of $320 \times 40 \text{ km}^2$. The minimum value at 670 nm of all the LER values falling in each $1^\circ \times 1^\circ$ grid cell per month acquired between June 1995 and December 2000 is stored in the data base. The minimum LER is expected to have the least cloud contamination. For the remaining ten channels, the corresponding values of the same spectrum are stored. Three correction steps are subsequently applied to account for remaining cloud effects over ocean, to remove (temporal) outliers, and to fill empty grid cells. The GOME LER data base was evaluated by comparison to the TOMS climatology (Herman and Celarier, 1997) for the UV channel at 380 nm and biases in the order of $\sim 0.007\text{--}0.023$ as well as standard deviations (σ) ~ 0.02 were found and judged as satisfactory (Koelemeijer et al., 2003). Fournier et al. (2006) corrected the underestimation of the surface albedo over deserts by empirically found 20%. Herein, we exclusively use this updated GOME data base. Figure 1 illustrates the differences between the GOME LER $1^\circ \times 1^\circ$ resolution and the MERIS $0.25^\circ \times 0.25^\circ$ resolution climatology for the month of July exemplified for a subset covering Europe. Superimposed in red are the outlines of the individual pixels of one SCIAMACHY orbit from 14 July 2006 where a valid vertical trace gas column could have been retrieved. Obviously, the level of detail is much more pronounced in the MERIS BSA data. Different landscape structures such as the Alpine mountain range can be much better observed in the MERIS map. Further, coastlines are distinctively better detectable in the MERIS BSA data, e.g. around the Iberian peninsula or along the African coast. It often appears in the GOME ($1^\circ \times 1^\circ$) dataset that grid cells along coastlines are filled with the ocean LER, e.g. Mediterranean islands like Corsica, Sardinia, Balearic islands, and to some extent Sicily are not captured at all. This mismatch can not only be assigned to GOME's

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



865 nm are highly correlated. The first principal component of the eigenvalues of the three channels accounts for more than 99.5% of the variance in the data suggesting that the MODIS-MERIS comparison provides valuable information about the quality of the MERIS channels at 754 nm and 775 nm. Finally, it should be noted that these two datasets are not completely independent since the MERIS Albedomap product uses MODIS derived aerosol parameters for atmospheric correction and BRDF parameters to infer the black- and white-sky albedo (cf. Sect. 3.1).

4.1.3 Statistical analysis

Scatter density plots of MERIS BSA (at 754 nm) versus GOME LER (at 758 nm) for the months of January and July, respectively, are given in Fig. 3. Snow masked pixels are excluded from the comparison. The marked cluster detectable at GOME LER values lower than 0.05 and MERIS BSA between approximately 0.1 and 0.4 can be assigned to pixels along coastlines (cf. Fig. 4) where the contrast between ocean and land pixels is relatively large in the NIR. These pixels are apparently misclassified in the GOME LER data base due to its relatively coarse spatial resolution and selection criteria (cf. Fig. 1). The second feature marked in Fig. 3 consists of pixels mostly from arid areas, like the Saharan desert. Obviously, the GOME LER is underestimated in January while MERIS BSA is slightly lower than GOME LER July in the desert grid cells. The scatter density plots also demonstrate that these areas belong to the brightest surfaces in the NIR (apart from snow which has been masked here). Accurate information about the reflectivity of those targets is of particular interest since FRESCO+ is especially sensitive to changes of large albedo values (cf. Eq. 1). The highest densities occur close to the bisecting line but the scatter is rather large.

The lower two scatter density plots in Fig. 3 illustrate MERIS BSA versus MODIS BSA for the months of January and July. In general, a very good agreement between the two datasets can be found for both months. In comparison to the GOME LER-MERIS BSA plots, the scatter is remarkably reduced and no clusters of large differences are detectable. Further, most values are almost perfectly aligned

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



along the bisecting line. The few higher MERIS albedo values for MODIS BSA between approximately 0.15 and 0.3 can mainly be assigned to pixels adjacent to snow covered areas, for example in the boreal forest of northern latitudes in January or in the Andes during July (cf. Fig. 4).

5 Table 1 summarizes selected statistical parameters from the comparison between the MERIS BSA, MODIS BSA, and GOME LER. 5% of all match-ups with the largest absolute difference are discarded from the calculation (but shown in the scatter density plot in Fig. 3) to reduce the impact of outliers (mostly residual snow). These statistics underline the findings from Fig. 3 discussed above. MERIS BSA compares better to MODIS BSA than to the GOME LER dataset. The correlation coefficient obtained for the comparison between MERIS and MODIS is 0.98 for the entire dataset and 0.98 and 0.97 for January and July, respectively. Comparing MERIS BSA to GOME LER results in correlation coefficients of ~ 0.8 . In addition, the linear regression coefficients reveal almost no offsets and slopes near unity for the MERIS BSA–MODIS BSA comparison. In contrary, usually relatively large offsets and slopes considerably smaller than one are found for the MERIS BSA–GOME LER comparison reflecting the large underestimation and mismatch along coastlines in the GOME LER dataset. It is also noteworthy that the average differences between the three datasets are in general clearly below 0.01, except for the MERIS channel at 775 nm and GOME channel at 772 nm which are slightly higher than 0.01. The average differences for the MERIS BSA–MODIS BSA comparison are below 1% of the average (snow excluded) MERIS BSA of the entire year (~ 0.28 at 858 nm). Further, the σ of the differences from the MERIS BSA–MODIS BSA comparisons are approximately three times smaller than from the MERIS BSA–GOME LER comparison. We calculated statistical parameters for all individual months of the year. With regard to the MERIS BSA–MODIS BSA comparison, this does not result in a seasonal pattern for any parameter. The smallest correlation coefficient is 0.97 for June and July, the largest average difference is about 0.002 for September. We conclude that the MERIS BSA data base compares well and considerably better than GOME LER to MODIS BSA.

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



values can be observed in central Africa and some regions in northern latitudes higher than 45°. Jin et al. (2003) speculated that probably intense biomass burning in the Amazon basin as well as land cover change can lead to differences when comparing albedo products over eastern South America. Apart from arid areas, the previously mentioned regions with deviating albedo values usually provide a very low number of high quality retrievals for the MODIS albedo and BRDF products due to persistent cloud coverage (tropics) or seasonal snow and cloud contamination (Gao et al., 2005; Moody et al., 2005). Some differences thus also appear because MODIS BSA uses a temporal interpolation technique but in the MERIS BSA data base the value from the closest month is assigned to missing grid cells. Finally, in the Saharan desert and the Arabian peninsula, MERIS BSA and MODIS BSA are in very good agreement.

The coastline mismatch of the GOME data base is pronounced in most areas of the world and for both months illustrated in Fig. 4, with the exception of tropical Africa, South America in winter and East Asia in summer. MERIS and GOME also reveal some large differences in arid regions, e.g. in the Saharan desert and the Arabian Peninsula in January or Australia and the Namib desert in July. Negative differences (GOME > MERIS, given in blue) in the tropics are likely due to an overestimation of GOME LER caused by residual cloud coverage near the Intertropical Convergence Zone (ITCZ), e.g. in South America, west coast of Africa or Asia (Koelemeijer et al., 2003). This difference follows the northward migration of the ITCZ from January to July. While MERIS BSA shows higher values than GOME for the Sahara and the Arabian peninsula in January, for many pixels the opposite is the case for July. Desert regions are challenging for surface albedo retrieval because of the presence of mineral dust and the usually high albedo of the surface. Dust aerosols lower the measured reflectance at the TOA through absorption so the minimum LER used to compile the GOME LER climatology does not correspond to the aerosol-free observation anymore. Although Fournier et al. (2006) corrected for this effect, the deviations between GOME and MERIS are still large when considering the good agreement between MERIS and MODIS. However, the MERIS and MODIS albedo products might be also strongly

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



affected by the presence of desert dust aerosols. Both products rely on the aerosol optical depth (AOD) retrieval over land from MODIS (Kaufman and Tanré, 1998) which does not provide AOD over bright surfaces like snow or desert (Remer et al., 2008). Therefore, aerosol parameters from predefined climatologies (cf., Vermote et al., 1997; Koepke et al., 1997) are used to derive surface reflectance in this case.

4.2 FRESCO+ results using MERIS albedo

4.2.1 Comparison to results from the GOME data base

The effect of the MERIS albedo climatology on O₂ A-band cloud retrieval is demonstrated using two exemplary months of SCIAMACHY data (January and July 2006). Global maps of monthly averaged effective cloud fraction obtained with the GOME LER and MERIS BSA datasets as well as their differences are depicted in Fig. 5. Differences generally follow the trend identified in Fig. 4 and discussed in the previous section. For example, the higher MERIS BSA over Western Australia results in much smaller effective cloud fractions in July. The relatively higher MERIS BSA over the Sahara and the Arabian peninsula in January leads to lower effective cloud fractions in these regions which is not the case for July. Increased aerosol abundance and absorption during summer might lead to an underestimation of surface albedo in arid regions and therefore an overestimation of cloud fraction. However, the MERIS BSA dataset results in a distinct smoother distribution of effective cloud fractions over these arid regions (also in July). We attribute this effect to the better spatial resolution of the MERIS BSA data base that allows a better representation of the quite heterogeneously distributed soils and rock types in the Saharan desert (cf. Tsvetsinskaya et al., 2002).

A more detailed view is given in Fig. 6 for a subset covering Europe and parts of North Africa. The effect of the MERIS climatology is clearly detectable for both months. Mediterranean islands like Corsica or Sicily have a strong impact on the water-land mismatch in the GOME LER dataset (cf. Fig. 1) leading to an overestimation of effective

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

cloud fraction. Mediterranean islands are not captured well by the GOME LER climatology in general. The increased effective cloud fractions along the northern African coast in the FRESCO+ GOME results are another example of the mismatch along coastlines. An improved effective cloud fraction retrieval from FRESCO+ in coastal areas is desirable considering that a majority of the world's largest megacities are located in the immediate vicinity to the ocean. Several studies underlined the scientific interest of air pollution assessments in these areas from spaceborne trace gas retrievals (e.g., Richter et al., 2005; van der A et al., 2008).

Scatter density plots of the cloud fractions obtained from the MERIS BSA data base as a function of the ones obtained from the GOME LER data base are illustrated in Fig. 7 for January and July 2006. In order to reduce the influence of snow contamination exclusively values obtained between 50° S and 50° N are plotted. The majority of points is aligned close to the bisecting line. The bimodal distribution of cloud fractions is mirrored by an increased number of very low and very high values. The largest differences are mostly observable for effective cloud fractions lower than ~ 0.3 . This on the one hand underlines that the impact of surface albedo is largest for small effective cloud fractions and on the other hand is of particular interest for trace gas retrievals which are restricted to relatively small cloud fractions (usually < 0.3). The effect of the higher surface reflectivity of arid regions (cf. Fig. 5) and the enhanced spectral contrast along coastlines (cf. Fig. 6) can be detected in Fig. 7 where the FRESCO+ GOME results reveal more enhanced effective cloud fractions for low values of the MERIS results than contrariwise. The feature of relatively low MERIS BSA cloud fractions for GOME LER cloud fractions higher than 0.3 in the January scatter density plot (Fig. 7a) can mainly be ascribed to the above-mentioned geographical areas, i.e. coastlines, deserts and occasionally to snow cover affected areas in northern latitudes. The correlation coefficients are high (0.94 for January and 0.96 for July), the offsets low (-0.008 for January and 0.00 for July) and the slopes almost unity (1.002 for January and 1.00 for July). However, the results based on MERIS BSA reveal lower mean cloud fraction for global snow/ice-free land surfaces between 50° S and 50° N, e.g. 0.30 versus 0.34

for GOME LER for January and 0.24 versus 0.26 for the month of July 2006 which underlines the general reduction of the artefacts mentioned above.

With regard to cloud pressure, use of the MERIS data base leads to similar results as the GOME LER. We consider exclusively cloud pressure for effective cloud fractions ≥ 0.1 (in accordance to Wang et al., 2008). The MERIS BSA results reveal slightly lower average cloud pressure for January 2006 (GOME: 677.4 hPa, MERIS: 666.9 hPa; difference: $10.5 \text{ hPa} \pm 58.1 \text{ hPa}$) and almost identical average cloud pressure for July 2006 (GOME: 684.4 hPa, MERIS: 683.9 hPa; difference: $0.5 \text{ hPa} \pm 48.1 \text{ hPa}$). In addition, the correlation coefficients between the two sets are very high (0.96 for January 2006 and 0.97 for July 2006). Koelemeijer et al. (2001) showed that cloud pressure is not very sensitive to changes in surface albedo. The reason is that cloud pressure is derived from the depth of the O_2 A-band and since O_2 is a strong absorber in this band, most of the light is absorbed before reaching the surface such that the reflected light from the surface has only a small impact on the retrieval.

4.2.2 Comparison to HICRU

The Heidelberg iterative cloud retrieval (HICRU, Grzegorski et al., 2006) provides effective cloud fraction and cloud top pressure from SCIAMACHY data and is used herein to evaluate the impact of the new albedo climatology on the FRESCO+ retrievals. HICRU is especially suitable for this purpose as it is based on the same concept of effective cloud fraction in contrast to other available cloud parameters from other algorithms (e.g. Kokhanovsky et al., 2009). In contrast to FRESCO+, HICRU takes advantage of the higher spatial resolution of the Polarization Monitoring Devices (PMD, $7 \times 30 \text{ km}^2$ across/along track) to derive cloud fraction. For each scene, HICRU first defines an upper intensity threshold representing fully cloudy SCIAMACHY pixels (I_{cloudy}) and a lower intensity threshold standing for the intensity of cloud free pixels ($I_{\text{cloudfree}}$). The effective cloud fraction is subsequently found by linear interpolation, i.e. by dividing the difference between the measured intensity and $I_{\text{cloudfree}}$ by $I_{\text{cloudy}} - I_{\text{cloudfree}}$. The lower intensity threshold is a priori determined by iterative image sequence analysis

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



of PMD3 (617–705 nm) intensities and is a function of longitude, latitude, and surface albedo. $I_{\text{cloudfree}}$ is mapped to a grid with a spatial resolution (latitude \times longitude) of $0.1^\circ \times 0.062^\circ$. The upper threshold is found by radiative transfer calculations and as a function of solar zenith and view zenith angles. A detailed description of the methodology can be found in Grzegorski et al. (2006) and Grzegorski (2009). The accuracy of the effective cloud fraction obviously depends on the two thresholds. HICRU fails in the presence of snow and ice because these surfaces are often brighter than clouds with high albedo.

Grzegorski et al. (2006) compared HICRU to FRESCO (for latitudes between 50° N and 50° S to avoid snow contamination) and found slightly better correlations over ocean than over land. In this study we exclusively compare results over land as the MERIS albedo data does not provide values over ocean. FRESCO+ reports effective cloud fraction corresponding to a Lambertian cloud albedo of 0.8 and HICRU derives I_{cloudy} as a function of the observation geometry with a fixed optical thickness of 50 and the assumption of a scattering cloud with a vertical extension of 1 km which approximately corresponds to a Lambertian cloud with an albedo of 0.9. In order to account for these different assumptions and for better comparability, we convert the FRESCO+ effective cloud fractions such that they correspond to a Lambertian cloud albedo of 0.9. An empirical relation (third order polynomial fit) between the ratio of the effective cloud fraction for a cloud albedo of 0.9 and 0.8 as a function of surface albedo has been established by running FRESCO+ for one SCIAMACHY orbit (4 February 2007, 10:30 UTC) for the two cloud albedo values (Fig. 8). Cloud fractions are henceforth restricted to values below 0.8 because retrieved effective cloud fractions higher than one are set to 1.0 in the original FRESCO+ retrieval leading to an upper limit of approximately 0.9 after the conversion.

Figure 9 demonstrates that the FRESCO+ MERIS results are in better agreement to the HICRU effective cloud fractions for both months than FRESCO+ GOME. Especially the overestimation of small cloud fractions where the impact of the surface reflectivity is large as well as the scattering are clearly reduced. The averaged FRESCO+–HICRU

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



5 difference decreases from 0.02 (0.03) to 0.00 (0.02) and the correlation increases from 0.93(0.92) to 0.96 (0.96) for January (and July, cf. Table 2). FRESCO+ effective cloud fractions lower than 0.075 for HICRU cloud fractions larger than 0.225 in the January plots can be assigned to residual snow signals mostly in the MERIS BSA climatology. However, overall less than 0.3% of all retrievals are affected, mostly in Canada ($\sim 90^\circ$ W, $> 40^\circ$ N) and Siberia ($\sim 100^\circ$ E, $> 40^\circ$ N, cf. Fig. 10).

10 Distinct improvements for FRESCO+ MERIS are achieved for a subregion covering the Sahara desert and Arabian peninsula [15° N– 30° N, 15° W– 60° E] for January 2006. The correlation coefficient increases from 0.75 to 0.92, the RMSE decreases from 0.13 to 0.05, and the averaged difference decreases from 0.08 to 0.01 (Table 2). In contrast, although the σ (from 0.08 to 0.05), RMSE (from 0.12 to 0.09), and correlation (from 0.62 to 0.76) improved, the averaged difference remains constant for July (Table 2). The MERIS and MODIS black-sky albedo are in very good agreement in this region throughout the year (e.g. in July $R = 0.99$, offset = -0.01 , slope = 1.02, difference of mean = 0.00). The better correlation, σ , and RMSE can be explained through the enhanced spatial resolution of the MERIS data base which better captures the heterogeneous surface features in the desert. As noted in Muller (2008) absorbing aerosols seriously hamper an accurate albedo retrieval. The study of de Graaf et al. (2005) revealed that the annual occurrence of desert dust is highest in the summer months which indicates that both, MERIS and MODIS black-sky albedo are underestimated for this time of the year. In addition, FRESCO+ effective cloud fractions are very sensitive to small changes of surface albedo values, especially over highly reflective targets. The following estimate of the change in effective cloud fraction due to changes in surface albedo is given in Koelemeijer et al. (2001):

$$25 \quad \Delta c = -\frac{1-c}{A_c - A_s} \Delta A_s \quad (2)$$

HICRU reveals an average effective cloud fraction (c) of 0.037 for July 2006 over the Saharan desert and Arabian peninsula (cf. Table 2), the mean A_s of MERIS in this area is 0.394, A_c of FRESCO+ is 0.9, and Δc is 0.07. Thus, disregarding all other error

sources, Eq. (2) suggests that MERIS BSA is underestimated by 0.035 (~9.0%) in July in the considered area.

Figure 10 presents global maps of the difference between FRESCO+ MERIS or GOME to HICRU. Again, FRESCO+ MERIS–HICRU reveals a smoother geographical distribution in comparison to FRESCO+ GOME–HICRU due to the better spatial resolution of the MERIS BSA data base. Both FRESCO+ retrievals occasionally underestimate effective cloud fraction in regions adjacent to snow covered areas, i.e. in the boreal forests in the northern hemisphere in January 2006. For January 2006, the obtained enhancements are particularly detectable over the above-mentioned arid regions but also over large parts of the Americas. FRESCO+ GOME underestimates effective cloud fractions in the ITCZ in both months, e.g. in Northern South America due to residual cloud signature in the GOME LER data base (Koelemeijer et al., 2003, cf. Fig. 4, Sect. 4.1.4). Taken together, we conclude that FRESCO+ MERIS is in clearly better agreement to HICRU than FRESCO+ GOME.

5 Conclusions

A new albedo climatology created from MERIS Albedomap data with the aim to enhance the operational retrieval of effective cloud fraction over land surfaces in the O₂ A-band was introduced. We tested the substitution of the 1° × 1° GOME LER climatology in the FRESCO+ cloud retrieval with this MERIS black-sky albedo dataset on a grid of 0.25° × 0.25°. Further, the MERIS climatology was compared to MODIS black-sky albedo and to the GOME LER data base. In order to assess the obtained improvements, FRESCO+ was run for two exemplary months of SCIAMACHY data (January and July 2006) and the results were related to retrievals from the cloud retrieval algorithm HICRU. The main findings can be summarized as follows:

1. The compiled MERIS BSA data base compares well to MODIS BSA data in the NIR. Correlation coefficients for the entire year are very high (0.98) with no bias

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

[Title Page](#)

[Abstract](#)

[Introduction](#)

[Conclusions](#)

[References](#)

[Tables](#)

[Figures](#)

[⏪](#)

[⏩](#)

[◀](#)

[▶](#)

[Back](#)

[Close](#)

[Full Screen / Esc](#)

[Printer-friendly Version](#)

[Interactive Discussion](#)



(< 1%) and only small σ (~ 0.017 or $\sim 6\%$). Comparing the MERIS BSA data base to GOME LER at around 760 nm leads to a lower correlation (0.80) and two clusters can clearly be identified in the corresponding scatter density plots which are related to the strong albedo contrasts along coastlines not resolved by the GOME LER as well as the underestimation of the GOME LER in arid regions in winter.

2. The largest differences between FRESCO+ MERIS BSA and FRESCO+ GOME retrievals are found for relatively small cloud fractions where the impact of the surface reflectance on the measured signal is largest. This is of particular interest because tropospheric trace gas retrievals are generally limited to small cloud fractions. The effect of the MERIS BSA dataset on the derivation of FRESCO+ cloud pressure is only minor.
3. Artefacts in cloud detection along coastlines due to the coarse resolution or water-land mismatching of GOME LER data base were successfully eliminated. This is of importance for spaceborne trace gas retrievals because inaccurate cloud parameters lead to inaccuracies in the air mass factor computations, especially in polluted regions (Boersma et al., 2004). A majority of the world's largest megacities are located in the immediate vicinity to the ocean and trace gas remote sensing retrievals are expected to be indirectly improved in these areas by incorporating the MERIS BSA data base into FRESCO+.
4. Using the MERIS data base in the FRESCO+ retrievals leads to a better agreement with HICRU for January and July 2006 on a global scale. The average difference of derived effective cloud fractions was reduced from 0.02 (0.03) to 0.00 (0.02) for the exemplary month of January 2006 (July 2006). The correlation improved from ~ 0.92 to 0.96 and RMSE decreased from 0.08 to 0.05.
5. Comparisons to HICRU also point out that effective cloud fractions over arid regions were successfully reduced and the spatial distribution became much

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

smoother with MERIS BSA. However, FRESCO+ MERIS effective cloud fractions over highly reflecting desert targets are still overestimated for summer months. One reason could be the presence of, or lack of accurate information about, absorbing aerosols in these areas which hampered the albedo retrieval. In addition, FRESCO+ effective cloud fractions are also very sensitive to small changes in surface reflectivity for high surface albedo values. Empirically derived correction factors might enhance the presented MERIS BSA dataset in arid regions in the future.

6. FRESCO+ MERIS also is in better agreement to HICRU in the ITCZ where FRESCO+ GOME underestimates effective cloud fraction over land due to residual cloud signatures in the surface albedo dataset.

The presented albedo climatology can also be applied to other cloud parameter retrieval algorithms from the O_2 A-band, e.g. to derive cloud top albedo from the Semi-Analytical CloUd retrieval Algorithm (SACURA, Kokhanovsky et al., 2003, 2006) or from the Retrieval Of Cloud Information using Neural Networks (ROCINN, Loyola et al., 2007). Although we concentrated in this study on the NIR channels relevant for O_2 A-band cloud retrievals, MERIS also measures radiances in spectral channels at 442 nm and 490 nm which could be used for cloud retrievals in the O_2 - O_2 absorption band around 477 nm (Acarreta et al., 2004) or to enhance spaceborne NO_2 retrievals. Previous studies demonstrated that using higher spatial resolution of forward model parameters can lead to more accurate estimates of NO_2 tropospheric column amount (Zhou et al., 2009, 2010). Relating MERIS black-sky albedo to MODIS around 440 nm showed similar enhancements as the comparison with GOME LER in the NIR. Furthermore, the MERIS BSA at 620 nm, 665 nm, and 681 nm can be integrated in current H_2O retrievals to consider the effect of surface reflectivity on the air mass factor (e.g. Wagner et al., 2003). However, the MERIS BSA data base is limited due to its spectral coverage to a wavelength range between 412 nm and 885 nm. It is therefore mainly interesting for trace gases with fitting windows in this wavelength range (e.g. NO_2) but

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

not for applications in the UV wavelengths region. The obtained improvements also have consequences for trace gas retrievals from UV/VIS sensors incorporating the FRESCO+ cloud products. Reprocessing of SCIAMACHY FRESCO+ retrievals with the new MERIS albedo data base is planned in the TEMIS project (www.temis.nl). Although we tested the applicability only on SCIAMACHY data, it is expected that similar advancements are obtained applying the FRESCO+ algorithm to any instrument which allows an O₂ A-band cloud retrieval (e.g. GOME or GOME-2).

Acknowledgements. We thank ESA for providing MERIS Albedomap and SCIAMACHY data as well as NASA for providing the MODIS snow product (MOD10CM) and spatially complete surface albedo products free of charge. We like to acknowledge Thomas Wagner (Max-Planck-Institute, Mainz, Germany) for fruitful discussions and thank Ronald van der A (KNMI) for the TEMIS data processing. PW was supported by the Netherlands Space Office project “SCIA-Visie”.

References

- Acarreta, J. R., de Haan, J. F., and Stammes, P.: Cloud pressure retrieval using the O₂-O₂ absorption band at 477 nm, *J. Geophys. Res.*, 109, D05204, doi:10.1029/2003JD003915, 2004. 4605, 4627
- Anderson, G. P., Clough, S. A., Kneizys, F. X., Chetwynd, J. H., and Shettle, E. P.: AFGL atmospheric constituent profiles, Tech. Rep. AFGL-TR-86-0110, Air Force Geophys. Lab, Hanscom AFB, Mass., 1986. 4608
- Boersma, K. F., Eskes, H. J., and Brinksma, E. J.: Error analysis for tropospheric NO₂ retrieval from space, *J. Geophys. Res.*, 109, D04311, doi:10.1029/2003JD003962, 2004. 4605, 4626
- de Graaf, M., Stammes, P., Torres, O., and Koelemeijer, R. B. A.: Absorbing Aerosol Index: Sensitivity analysis, application to GOME and comparison with TOMS, *J. Geophys. Res.*, 110, D01201, doi:10.1029/2004JD005178, 2005. 4624
- Fournier, N., Stammes, P., de Graaf, M., van der A, R., Piters, A., Grzegorski, M., and Kokhanovsky, A.: Improving cloud information over deserts from SCIAMACHY Oxygen A-band measurements, *Atmos. Chem. Phys.*, 6, 163–172, doi:10.5194/acp-6-163-2006, 2006. 4608, 4614, 4619

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

Gao, F., Schaaf, C. B., Strahler, A. H., Roesch, A., Lucht, W., and Dickinson, R.: MODIS bidirectional reflectance distribution function and albedo Climate Modeling Grid products and the variability of albedo for major global vegetation types, *J. Geophys. Res.*, 110, D01104, doi:10.1029/2004JD005190, 2005. 4619

5 Grzegorski, M., Wenig, M., Platt, U., Stammes, P., Fournier, N., and Wagner, T.: The Heidelberg iterative cloud retrieval utilities (HICRU) and its application to GOME data, *Atmos. Chem. Phys.*, 6, 4461–4476, doi:10.5194/acp-6-4461-2006, 2006. 4605, 4622, 4623

Grzegorski, M.: Cloud retrieval from UV/VIS satellite instruments (SCIAMACHY and GOME), PhD thesis, University of Heidelberg, Germany, 2009. 4623

10 Hall, D. K., Riggs, G. A., Salomonson, V. V., DiGirolamo, N. E., and Bayr, K. J.: MODIS Snow-Cover Products, *Remote Sens. Environ.*, 83(1–2), 181–194, 2002. 4611

Herman, J. R. and Celarier, E. A.: Earth surface reflectivity climatology at 340–380 nm from TOMS data, *J. Geophys. Res.*, 102, 28003–28011, 1997. 4608, 4614

15 Jin, Y., Schaaf, C. B., Woodstock, C. E., Gao, F., Li, X., Strahler, A. H., Lucht, W., and Liang, S.: Consistency of MODIS surface bidirectional reflectance distribution function and albedo retrievals: 2. Validation, *J. Geophys. Res.*, 108(D5), 4159, doi:10.1029/2002JD002804, 2003. 4619

Kaufmann Y. J. and Tanré, D.: Algorithm for remote sensing of tropospheric aerosol from MODIS, NASA Algorithm Theoretical Basis Document, Product ID: MOD04, 1998. 4610, 4620

20 Kleipool, Q. L., Dobber, M. R., de Haan, J. F., and Levelt, P. F.: Earth surface reflectance climatology from 3 years of OMI data, *J. Geophys. Res.*, 113, D18308, doi:10.1029/2008JD010290, 2008. 4612, 4613

25 Koелеmeijer, R. B. A., Stammes, P., Hovenier, J. W., and de Haan, J. F.: A fast method for retrieval of cloud pa-rameters using oxygen A-band measurements from the Global Ozone Monitoring Experiment, *J. Geophys. Res.*, 106(D4), 3475–3490, 2001. 4605, 4606, 4607, 4608, 4609, 4622, 4624

Koелеmeijer, R. B. A., de Haan, J. F., and Stammes, P.: A database of spectral surface reflectivity in the range 335–772 nm derived from 5.5 years of GOME observations, *J. Geophys. Res.*, 108(D2), 4070, doi:10.1029/2002JD002429, 2003. 4606, 4608, 4612, 4613, 4614, 4619, 4625

30 Koepke, P., Hess, M., Schult, I., and Shettle, E. P.: Global Aerosol Data Set, MPI Report No. 243, Max-Planck-Institut für Meteorologie, Hamburg, Germany, 1997. 4610, 4620

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Kokhanovsky, A. A., Rozanov, V. V., Zege, E. P., Bovensmann, H., and Burrows, J. P.: A semianalytical cloud retrieval algorithm using backscattered radiation in 0.4–2.4 μm spectral region, *J. Geophys. Res.*, 108(D1), 4008, doi:10.1029/2001JD001543, 2003. 4627
- 5 Kokhanovsky, A. A., Rozanov, V. V., Nauss, T., Reudenbach, C., Daniel, J. S., Miller, H. L., and Burrows, J. P.: The semianalytical cloud retrieval algorithm for SCIAMACHY I. The validation, *Atmos. Chem. Phys.*, 6, 1905–1911, doi:10.5194/acp-6-1905-2006, 2006. 4605, 4627
- Kokhanovsky, A. A., von Hoyningen-Huene, W., and Burrows, J. P.: Determination of the cloud fraction in the SCIAMACHY ground scene using MERIS spectral measurements, *Int. J. Remote Sens.*, 30(23), 6151–6167, 2009. 4609, 4622
- 10 Krijger, J. M., van Weele, M., Aben, I., and Frey, R.: Technical Note: The effect of sensor resolution on the number of cloud-free observations from space, *Atmos. Chem. Phys.*, 7, 2881–2891, doi:10.5194/acp-7-2881-2007, 2007. 4605
- Liu, J., Schaaf, C., Strahler, A., Jiao, Z., Shuai, Y., Zhang, Q., Roman, M., Augustine, J. A., and Dutton, E. G.: Validation of Moderate Resolution Imaging Spectroradiometer (MODIS) albedo retrieval algorithm: Dependence of albedo on solar zenith angle, *J. Geophys. Res.*, 114, D01106, doi:10.1029/2008JD009969, 2009. 4613
- 15 Loyola, D., Thomas, W., Livschitz, Y., Ruppert, T., Albert, P., and Hollmann, R.: Cloud properties derived from GOME/ERS-2 backscatter data for trace gas retrieval, *IEEE T. Geosci. Remote*, 45/9, 2747–2758, 2007. 4605, 4627
- 20 Moody, E., King, M., Platnick, S., Schaaf, C., and Gao, F.: Spatially Complete Global Spectral Surface Albedos: Value-Added Datasets Derived From Terra MODIS Land Products, *IEEE T. Geosci. Remote*, 43, 144–158, 2005. 4619
- Moody, E. G., King, M. D., Schaaf, C. B., and Platnick, S.: MODIS-derived spatially complete surface albedo products: Spatial and temporal pixel distribution and zonal averages, *J. Appl. Meteorol. Clim.*, 47, 2879–2894, 2008. 4613, 4615
- 25 Muller, J.-P.: MERIS GLOBAL LAND SURFACE ALBEDO MAPS: Algorithm Theoretical Basis Document ATBD 1.4 BRDF/ALBEDO RETRIEVAL, available at: http://www.brockmann-consult.de/albedomap/pdf/MERIS-AlbedoMap-ATBD_BRDF_Albedo-1.0.pdf, last acces: 26 October 2010, 2006. 4606, 4610, 4624
- 30 Oleson, K. W., Bonan, G. B., Schaaf, C. B., Gao, F., Jin, Y., and Strahler, A.: Assessment of global climate model land surface albedo using MODIS data, *Geophys. Res. Lett.*, 30(8), 1443, doi:10.1029/2002GL016749, 2003. 4613

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

[Title Page](#)
[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

- Preusker, R., Hünerbein, A., Fischer, J., Brockmann, C., and Krämer, U.: MERIS GLOBAL LAND SURFACE ALBEDO MAPS: ATBD Cloud detection, available at: http://www.brockmann-consult.de/albedomap/pdf/atbd_cloud_detection_omap_5.pdf, last access: 26 October 2010, 2008. 4610, 4612
- 5 Remer, L. A., Kleidman, R. G., Levy, R. C., et al.: Global aerosol climatology from the MODIS satellite sensors, *J. Geophys. Res.*, 113, D14S07, doi:10.1029/2007JD009661, 2008. 4620
- Richter, A., Burrows, J. P., Nüß, H., Granier, C., and Niemeier, U.: Increase in tropospheric nitrogen dioxide over China observed from space, *Nature*, 437, 129–132, doi:10.1038/nature04092, 2005. 4621
- 10 Schaaf, C. B., Gao, F., Strahler, A. H., Lucht, W., Li, X., Tsang, T., Strugnell, N., Xiaoyang, Z., Jin, Y., Muller, J.-P., Lewis, P., Barnsley, M. J., Hobson, P. H., Disney, M. I., Roberts, G., Dunderdale, M., Doll, C., D'Entremont, R. P., Hu, B., Liang, S., Privette, J. L., and Roy, D.: First operational BRDF, albedo nadir reflectance products from MODIS, *Remote Sens. Environ.*, 83, 135–148, 2002. 4606, 4610, 4611, 4615
- 15 Schroeder, T., Preusker, R., Schaale, M., and Fischer, J.: MERIS GLOBAL LAND SURFACE ALBEDO MAP, Algorithm Theoretical Document ATBD 1.2 Aerosol Correction, available at: http://www.brockmann-consult.de/albedomap/pdf/atbd.1_3.aerosol_corr_AMAP.pdf, last access: 26 October 2010, 2005. 4610
- 20 Stammes, P., Sneep, M., de Haan, J. F., Veefkind, J. P., Wang, P., and Levelt, P. F.: Effective cloud fractions from the Ozone Monitoring Instrument: Theoretical framework and validation, *J. Geophys. Res.*, 113, D16S38, doi:10.1029/2007JD008820, 2008. 4609
- Tuinder, O. N. E., de Winter-Sorkina, R., and Bultjes, P. J. H.: Retrieval methods of effective cloud cover from the GOME instrument: an intercomparison, *Atmos. Chem. Phys.*, 4, 255–273, doi:10.5194/acp-4-255-2004, 2004. 4609
- 25 Tsvetsinskaya, E. A., Schaaf, C. B., Gao, F., Strahler, A. H., Dickinson, R. E., Zeng, X., and Lucht, W.: Relating MODIS-derived surface albedo to soils and rock types over Northern Africa and the Arabian peninsula, *Geophys. Res. Lett.*, 29(9), 1353, doi:10.1029/2001GL014096, 2002. 4620
- 30 van der A, R. J., Eskes, H. J., Boersma, K. F., van Noije, T. P. C., Van Roozendaal, M., De Smedt, I., Peters, D. H. M. U., and Meijer, E. W.: Trends, seasonal variability and dominant NO_x source derived from a ten year record of NO₂ measured from space, *J. Geophys. Res.*, 113, D04302, doi:10.1029/2007JD009021, 2008. 4621

MERIS albedo climatology for FRESCO+

C. Popp et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Vasilkov, A., Joiner, J., Spurr, R., Bhartia, P. K., Levelt, P., and Stephens, G.: Evaluation of the OMI cloud pressures derived from rotational Raman scattering by comparisons with other satellite data and radiative transfer simulations, *J. Geophys. Res.*, 113, D15S19, doi:10.1029/2007JD008689, 2008. 4605
- 5 Vermote, E. F., El Saleous, N., Justice, C. O., Kaufman, Y. J., Privette, J. L., Remer, L., Roger, J. C., and Tanré, D.: Atmospheric correction of visible to middle-infrared EOS-MODIS data over land surfaces: Background, operational algorithm and validation, *J. Geophys. Res.*, 102(D14), 17131-17141, 1997. 4620
- 10 Wagner, T., Heland, J., Zöger, M., and Platt, U.: A fast H₂O total column density product from GOME - Validation with in-situ aircraft measurements, *Atmos. Chem. Phys.*, 3, 651–663, doi:10.5194/acp-3-651-2003, 2003. 4627
- Wagner, T., Beirle, S., Deutschmann, T., Grzegorski, M., and Platt, U.: Dependence of cloud properties derived from spectrally resolved visible satellite observations on surface temperature, *Atmos. Chem. Phys.*, 8, 2299–2312, doi:10.5194/acp-8-2299-2008, 2008. 4605
- 15 Wang, P., Stammes, P., van der A, R., Pinardi, G., and van Roozendael, M.: FRESCO+: an improved O₂ A-band cloud retrieval algorithm for tropospheric trace gas retrievals, *Atmos. Chem. Phys.*, 8, 6565–6576, doi:10.5194/acp-8-6565-2008, 2008. 4605, 4606, 4607, 4608, 4622
- 20 Zhou, Y., Brunner, D., Boersma, K. F., Dirksen, R., and Wang, P.: An improved tropospheric NO₂ retrieval for OMI observations in the vicinity of mountainous terrain, *Atmos. Meas. Tech.*, 2, 401–416, doi:10.5194/amt-2-401-2009, 2009. 4627
- Zhou, Y., Brunner, D., Spurr, R. J. D., Boersma, K. F., Sneep, M., Popp, C., and Buchmann, B.: Accounting for surface reflectance anisotropy in satellite retrievals of tropospheric NO₂, *Atmos. Meas. Tech.*, 3, 1185–1203, doi:10.5194/amt-3-1185-2010, 2010. 4618, 4627

MERIS albedo climatology for FRESCO+

C. Popp et al.

Table 1. Comparison between GOME LER, MERIS BSA, and MODIS BSA for snow-free pixels.

		R^1	average difference	σ^2	offset	slope
Whole Year	GOME 758 nm–MERIS 754 nm	0.80	-0.002	0.057	0.067	0.730
	GOME 772 nm–MERIS 775 nm	0.81	-0.013	0.057	0.078	0.733
	MODIS 858 nm–MERIS 865 nm	0.98	0.000	0.017	-0.001	1.005
January	GOME 758 nm–MERIS 754 nm	0.79	-0.005	0.063	0.057	0.792
	GOME 772 nm–MERIS 775 nm	0.80	-0.016	0.062	0.068	0.795
	MODIS 858 nm–MERIS 865 nm	0.98	-0.002	0.018	0.001	1.002
July	GOME 758 nm–MERIS 754 nm	0.79	-0.002	0.056	0.092	0.637
	GOME 772 nm–MERIS 775 nm	0.79	-0.014	0.056	0.103	0.642
	MODIS 858 nm–MERIS 865 nm	0.97	-0.001	0.016	0.005	0.984

¹ R : correlation coefficient;² σ : standard deviation of differences.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

Table 2. Comparison between FRESCO+ GOME/MERIS and HICRU cloud fraction over snow/ice-free land surfaces between 50° N and 50° S as well as over a subscene containing the Saharan desert and the Arabian peninsula [15° N–30° N and 15° W–60° E]. In FRESCO+, a cloud albedo of 0.9 is used and only cloud fractions < 0.8 are considered.

		$\overline{\text{FRESCO+} - \text{HICRU}}^1$	N^2	R^3	σ^4	offset	slope	RMSE ⁵
Global								
January	FRESCO+ GOME	0.02	124 455	0.93	0.06	0.02	0.96	0.08
	FRESCO+ MERIS	0.00	124 455	0.96	0.04	0.00	0.99	0.05
July	FRESCO+ GOME	0.03	154 663	0.92	0.06	0.03	0.99	0.08
	FRESCO+ MERIS	0.02	154 663	0.96	0.04	0.01	1.04	0.06
Saharan desert and Arabian peninsula								
January	FRESCO+ GOME	0.08	14 203	0.75	0.09	0.06	0.93	0.13
	FRESCO+ MERIS	0.01	14 203	0.92	0.03	0.02	0.81	0.05
July	FRESCO+ GOME	0.07	15 540	0.62	0.08	0.04	1.05	0.12
	FRESCO+ MERIS	0.07	15 540	0.76	0.05	0.07	0.92	0.09

¹ $\overline{\text{FRESCO+} - \text{HICRU}}$: average difference between FRESCO+ and HICRU;

² N : number of match-ups;

³ R : correlation coefficient;

⁴ σ : standard deviation of $\text{FRESCO+} - \text{HICRU}$;

⁵ RMSE: root mean square error.

[Title Page](#)
[Abstract](#)
[Introduction](#)
[Conclusions](#)
[References](#)
[Tables](#)
[Figures](#)
[◀](#)
[▶](#)
[◀](#)
[▶](#)
[Back](#)
[Close](#)
[Full Screen / Esc](#)
[Printer-friendly Version](#)
[Interactive Discussion](#)


**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

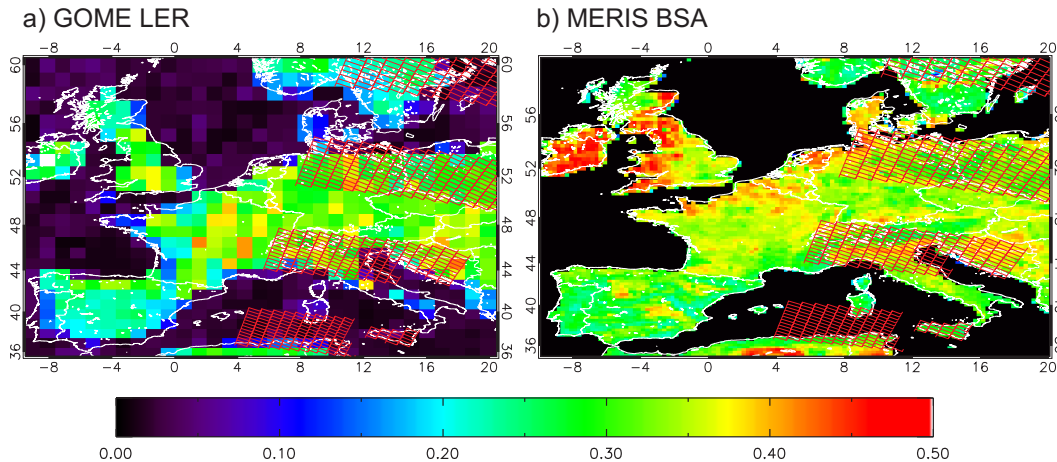


Fig. 1. Comparison between GOME LER with a spatial resolution of $1^\circ \times 1^\circ$ (758 nm) and MERIS BSA (754 nm) with a spatial resolution of $0.25^\circ \times 0.25^\circ$ for the month of July over Europe. Superimposed in red are the outlines of the SCIAMACHY pixels ($30 \times 60 \text{ km}^2$) for an orbit from 14 July 2006. Note that no albedo values over ocean are available for the MERIS data.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

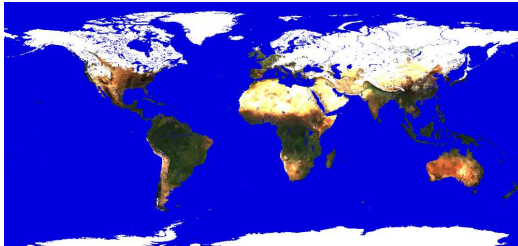
Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

a) January



b) July

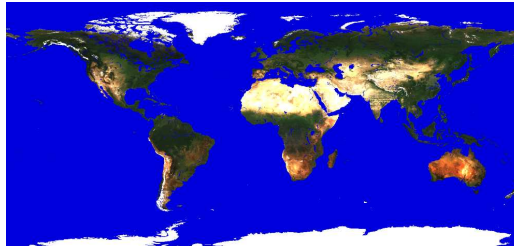


Fig. 2. RGB composites for the MERIS BSA dataset for January (left) and July (R: 665 nm, G: 650 nm, B: 490 nm). Oceans are filled with an artificial blue color.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

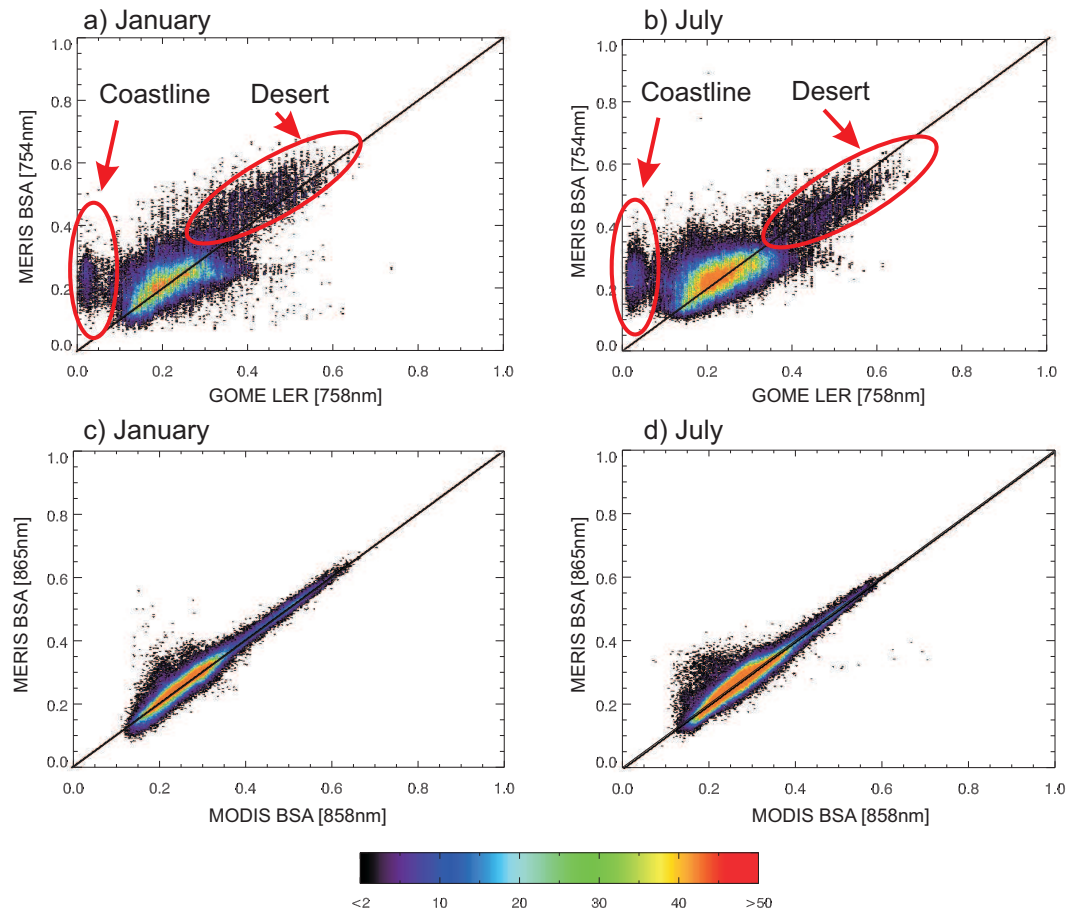


Fig. 3. Scatter density plots of MERIS BSA as a function of GOME LER and MODIS BSA for January and July for the NIR wavelength region. Only snow/ice-free grid cells over land are compared.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

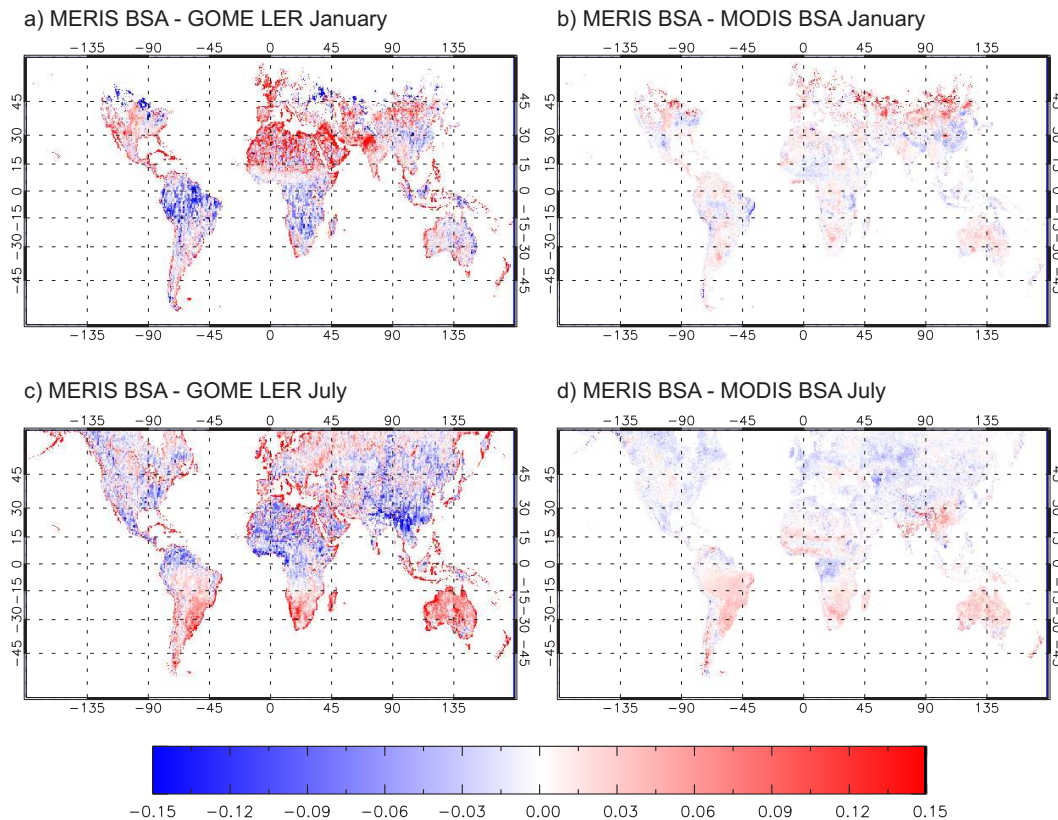


Fig. 4. Difference maps of MERIS BSA–GOME LER (754 nm and 758 nm) and MERIS BSA–MODIS BSA (865 nm and 858 nm) for January and July, respectively.

MERIS albedo climatology for FRESCO+

C. Popp et al.

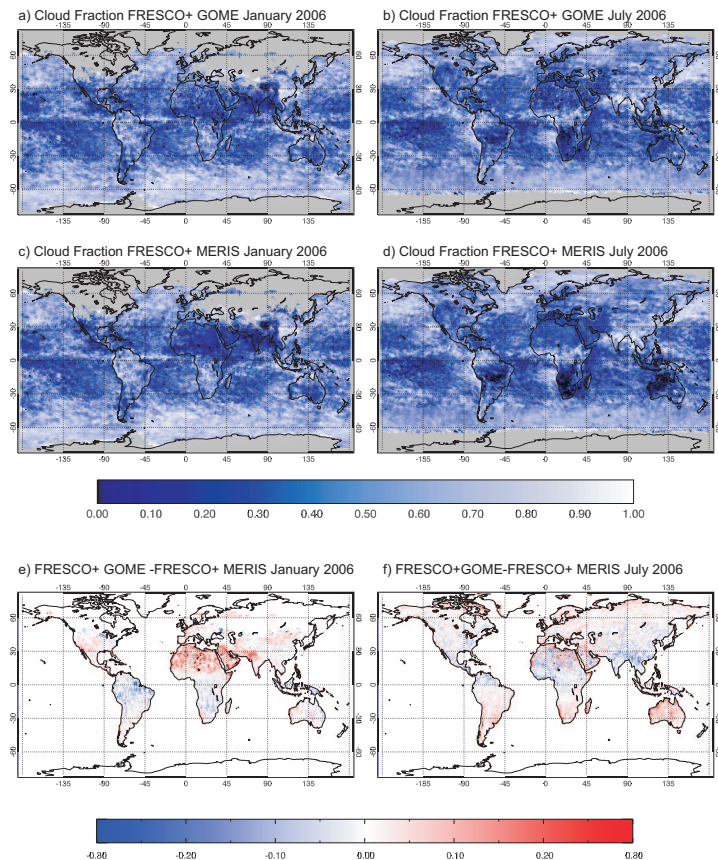


Fig. 5. Monthly mean FRESCO+ GOME and FRESCO+ MERIS effective cloud fraction (**a–d**) as well as their absolute differences (**e–f**) for January and July 2006. Note that ocean pixels are processed with the GOME LER data also in the MERIS retrieval so that no differences occur over water. Grid cells with no valid retrieval, e.g. due to permanent snow coverage are given in a grey color.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo climatology for FRESCO+

C. Popp et al.

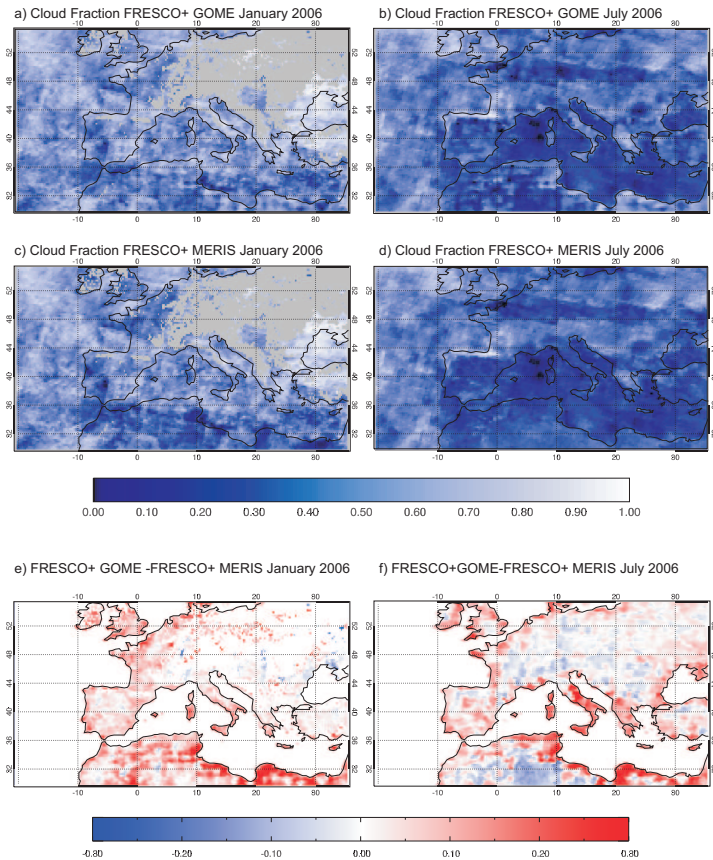


Fig. 6. Monthly mean FRESCO+ GOME and FRESCO+ MERIS effective cloud fraction (**a–d**) as well as their absolute differences (**e–f**) over Europe for January and July 2006. Note that ocean pixels are processed with the GOME LER data also in the MERIS retrieval so that no differences occur over water. Grid cells with no valid retrieval, e.g. due to permanent snow coverage are given in a grey color.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

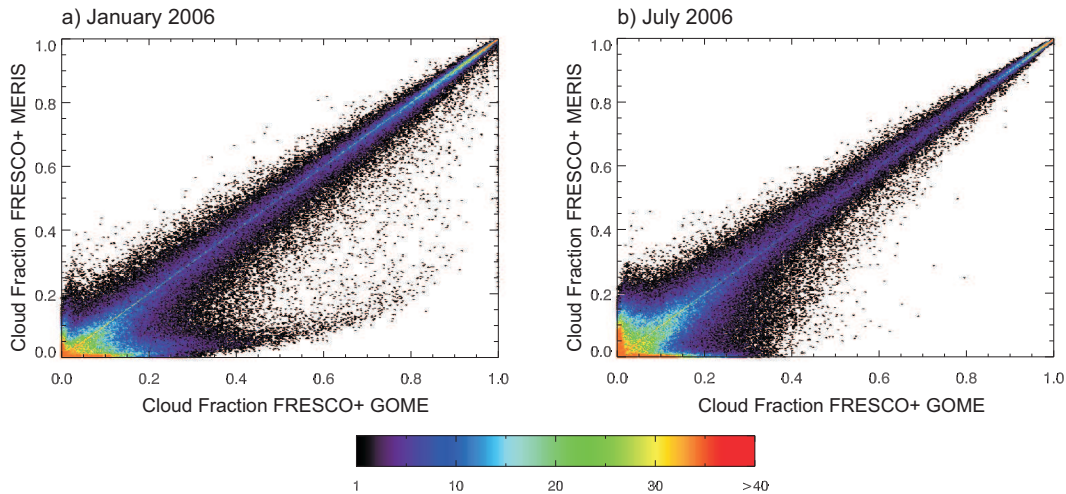


Fig. 7. Scatter density plots of FRESCO+MERIS effective cloud fraction as a function of FRESCO+GOME effective cloud fraction for January (left) and July 2006 (right). Only snow/ice-free values over land are compared.

[Title Page](#)[Abstract](#)[Introduction](#)[Conclusions](#)[References](#)[Tables](#)[Figures](#)[◀](#)[▶](#)[◀](#)[▶](#)[Back](#)[Close](#)[Full Screen / Esc](#)[Printer-friendly Version](#)[Interactive Discussion](#)

**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

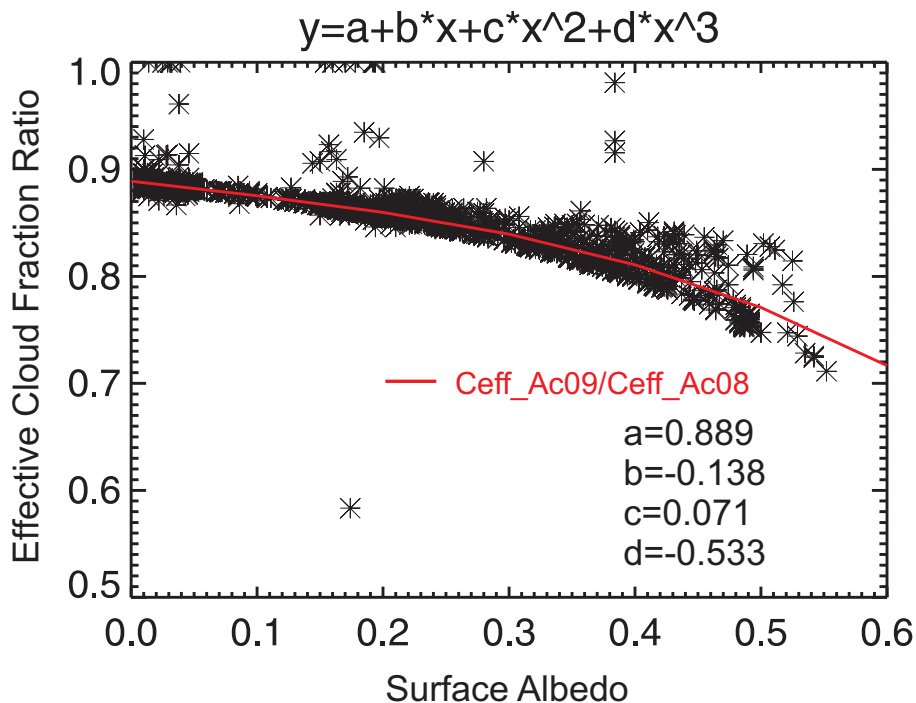


Fig. 8. Ratio of FRESCO+ effective cloud fractions for an assumed cloud albedo of 0.9 and 0.8, respectively. Based on FRESCO+ retrievals from one SCIAMACHY orbit (4 February 2007, 10:30 UTC).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**MERIS albedo
climatology for
FRESCO+**

C. Popp et al.

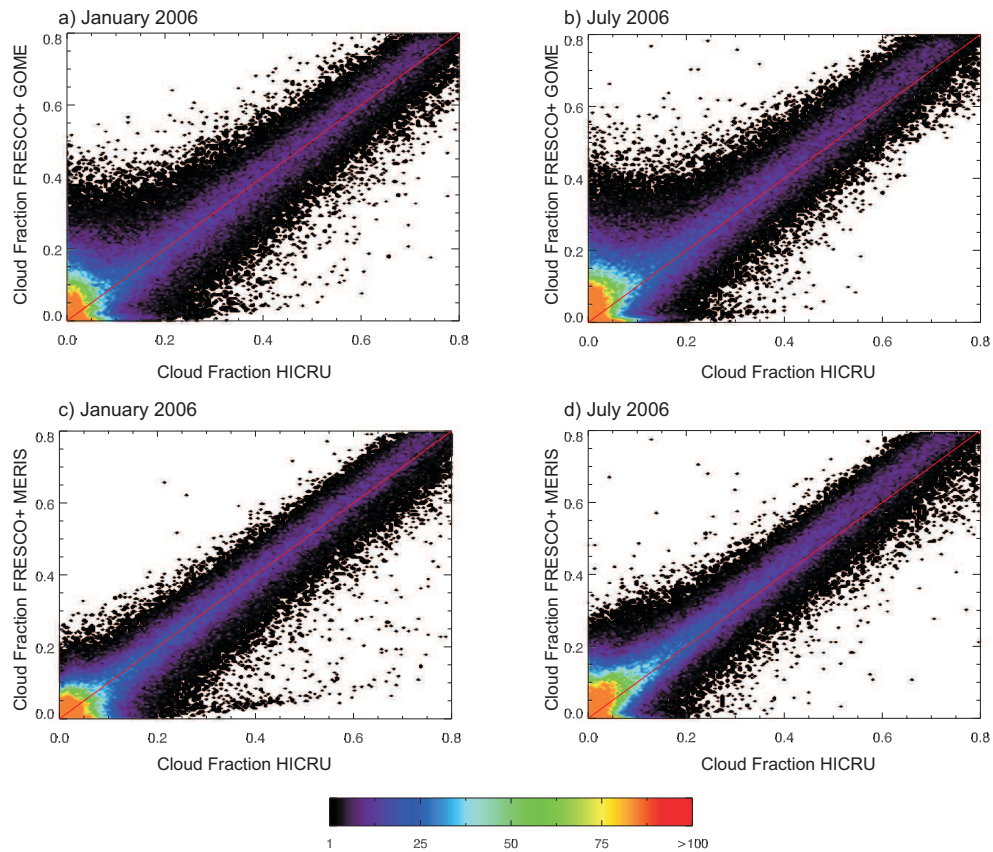


Fig. 9. FRESCO+ effective cloud fractions (upper panels with GOME LER, lower panels with MERIS BSA) as a function of HICRU cloud fractions for latitudes between 50° N and 50° S and snow/ice-free observations and for January (left) and July 2006 (right), respectively. FRESCO+ effective cloud fractions are converted to a cloud albedo of 0.9 and only cloud fractions < 0.8 are considered (see text).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

⏪

⏩

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



MERIS albedo
climatology for
FRESCO+

C. Popp et al.

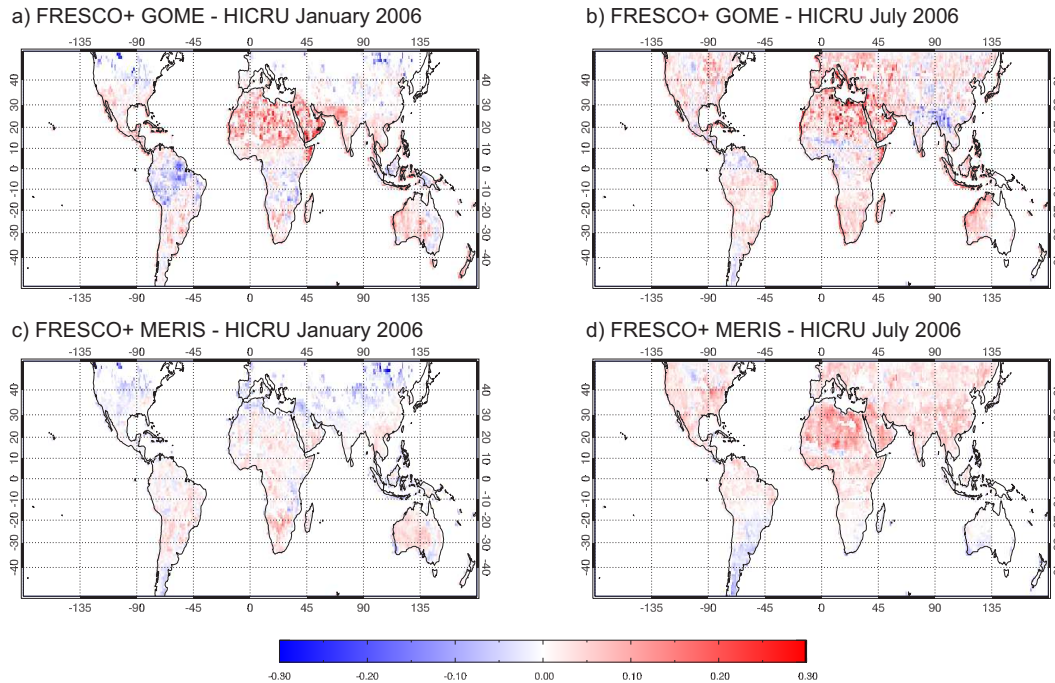


Fig. 10. Difference maps of monthly averaged effective cloud fractions per $1^\circ \times 1^\circ$ grid box between FRESCO+ (GOME (upper plots) and MERIS (lower plots)) and HICRU cloud fractions for January and July 2006. FRESCO+ effective cloud fractions are converted to a cloud albedo of 0.9 and only cloud fractions < 0.8 are considered (see text).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

