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A COMPARISON OF TOTAL SHORTWAVE SURFACE ALBEDO RETRIEVALS FROM MODIS AND TM DATA

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ABSTRACT:

Total shortwave albedo is one key variable controlling the radiation energy budget of the land surface. Thus, the monitoring of its spatial and temporal variations is one important issue e.g. for the application of climate models. Routine albedo products are available from the Moderate Resolution Imaging Spectroradiometer (MODIS), e.g. MODIS MCD43A3 as 16-day 500m combined product generated from data of Terra and Aqua MODIS. Furthermore, surface spectral reflectances from monotemporal multispectral sensor data may be used to estimate broadband albedos; for this purpose, conversion formulae have been developed for a number of sensors. Mismatches between different albedo products may arise e.g. from the atmospheric correction process, different scan view geometries, BRDF adjustments, the range of wavelengths used or the particular narrowband to broadband conversion formulae. In this study, albedo retrievals from Thematic Mapper (TM) data and MODIS data/products were analysed for their consistency. In detail, the following MODIS products were considered: MOD09 - daily bidirectional surface reflectance, and 16 days albedo-product MCD43A3. To allow a comprehensible comparison between TM and MODIS, TM data have been aggregated to 500m MODIS resolution using the Point Spread Function (PSF) of MODIS. The analysis was performed for different acquisition periods, which resulted in different levels of consistency and thus uncertainties associated with the particular products.

1. INTRODUCTION

Currently a number of satellite sensors are used to receive information about the reflectance of the earth´s surface. As a key parameter controlling the radiation budget and thus the energy budget of the surface, the hemispherical reflectance called albedo is required by climate models as input parameter. With the appearance of routine albedo products derived from data of satellite sensors like MODIS (Gao et al., 2005; Lucht et al., 2000; Schaaf et al., 2002) and the Multi-angle Imaging SpectroRadiometer (MISR) (Martonchik et al. 1998), albedo data sets with different spatial and temporal resolutions have become available. In addition to automatically generated albedo composites, a derivation of daily albedo from provided surface reflectances is also possible. Effects by scan view geometry, atmospheric correction or spectral interpolation remain to distort the signal and cause uncertainties and variabilities between the data derived from different sensor types.

Therefore the main issue of this paper was the use of MODIS (500m) and TM (30m) data to derive and compare data fields of shortwave broadband albedo. As method for converting reflectance values to albedo, the conversion formulae of Liang (2000) were applied to atmospherically corrected MODIS and TM data. A validation of the calculated albedo was achieved by the MODIS albedo product MCD43A3 ("black-sky" albedo under clear-sky conditions, 0.25-5µm). This product is derived by means of a semi-empirical BRDF model using 16-day observations (Liu et al., 2009).

The bidirectional spectral reflectance received bandwise from satellite observations equals surface spectral albedo under the assumption of Lambertian surfaces. To retrieve the broadband albedo from narrowband sensors, Liang (2000) developed formulae based on radiative transfer simulations that incorporated many different atmospheric conditions and surface reflectance spectra (taken from spectral libraries and AVIRIS-Airborne Visible/Infrared Imaging Spectrometer data). In our study, the formulae for MODIS and TM broadband albedo were verified using ideal (simulated) data prior their application to real sensor data.

2. SATELLITE DATA AND STUDY SITE

MODIS is an instrument onboard the Earth Observing System (EOS)-AM1 (Terra) and EOS-PM1 (Aqua). Designed as an opto-mechanical cross-track scanner, MODIS is observing nearly the entire earth every two days. The scanner receives radiances in 36 spectral bands with 250m, 500m and 1km geometric instantaneous-fields-of-view (GIFOV´s) at nadir. The bands numbered 1-2 with 250m GIFOV and the bands 3-7 with 500m GIFOV are responsible for observing land cover features as well as cloud and aerosol properties (Barnes et al., 1998). The spectral coverage of the bands is very similar to Landsat TM bands (Figure 5), only for MODIS band 5 there is no correspondent.

In this study, the MODIS products MOD09GA and MCD43A3 were used. The bidirectional reflectance product MOD09GA contains an estimate of the surface spectral reflectance without atmospheric influences like scattering or absorption. The used bands cover the spectral range from 0.459 to 2.155µm . The albedo product MCD43A3 covers 16 days of observation and provides both directional hemispherical reflectance (black-sky albedo) and bihemispherical reflectance (white-sky albedo). Both data products (surface reflectance and albedo) are available as a gridded data set in sinusoidal projection with a geometric resolution of 500m and were received for this study through the NASA "Warehouse Inventory Search Tool" (WIST).

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The multispectral sensor TM captures high spatial resolution scenes onboard the Landsat-5 platform. The instrument has the capability to observe earth's surface via a set of six reflective bands with wavelengths ranging from 0.45 to 2.35µm (Figure 5) and a geometric resolution of 30m at nadir. With a revisit cycle of 16 days, one of the sensor's major applications is the monitoring of land cover and land cover changes, although the operational use of the data is often limited by a restricted availability of cloud-free observations.

For our analysis, the following acquisition dates have been selected (by reason of clear-sky conditions and availability of both Terra MODIS and TM data): 19 July 2003, 4 August 2003 and 28 May 2005. Changes of atmospheric and surface conditions due to different overpass times of Terra MODIS and Landsat-5 TM were assumed to be negligible. At all dates, data were taken from the same satellite paths.

The study site was located in western Rhineland-Palatinate (Germany) close-by Luxembourg and had a size of approximately 2000 km² (Figure 1). The heterogeneous land cover included different types of forests, grassland, cropland and some urban settlements.

Figure 1. Subset of the MODIS data set (19 July 2003) with the TM scene near the edge of the scan swath. The red line illustrates the MODIS nadir line

To test the performance of broadband albedo conversion formulae, ideal MODIS and TM data have been simulated using a HyMap dataset (cf. chapter 3.1). The airborne hyperspectral scanner HyMap^{TM} operates over a wavelength range from 0.44 to 2.5µm. With a narrow bandwidth of 10-20nm the sensor is used as a nearly continuous spectrometer for tasks like environmental pollution monitoring, agriculture and forestry as well as soil and natural vegetation mapping (Cocks et al., 1998). The HyMap data (126 spectral bands, acquisition date 28 May 2005) covered an area that is 2.8km wide, 13km long and extends from the city of Trier (Rhineland-Palatinate, Germany) northwestbound. After an across-track illumination correction, the atmospheric correction was performed with the FLAASH (Fast Line of-sight Atmospheric Analysis of Spectral Hypercubes) module of ENVI^{TM}. The geometric correction was accomplished with the Parge^{TM} software (see Vohland et al., 2010).

The implemented radiometric correction of the Landsat-5 TM data comprised sensor calibration and full radiative transfer modelling; earth's surface was assumed to be a Lambertian. Pre-processing of the TM data from 28 May 2005 was validated with the HyMap dataset; the radiometric consistency of all three TM scenes was validated using a set of pseudo-invariant objects.

3. METHODOLOGY

Different terminologies of albedo exist why a systematic definition is necessary. "Inherent albedo" can be distinguished from "apparent albedo". Inherent albedo at a given solar zenith angle and wavelength solely depends on surface properties and thus is independent from the current atmospheric conditions.

Apparent albedo is defined as the ratio of upwelling irradiance to downward irradiance in dependency of solar zenith angle and wavelength. By the influence of the total downward radiance (direct and diffuse), apparent albedo is obviously a function of atmospheric conditions (Liang et al., 1999). This implies that apparent albedo received via remote sensing systems under specific conditions of the atmosphere may not be suitable for an application to other atmospheric conditions. The distribution of the downward flux after passing through the atmosphere is the weighting function for converting spectral albedo to broadband albedo. Apparent albedo is equivalent to the measurands registered by albedometers or pyranometers in the field (Liang, 2000). In absence of an atmosphere inherent albedo would be equivalent to apparent albedo.

To retrieve the broadband albedo from narrowband sensors a method based on radiative transfer simulations has been developed by Liang (2000). The formulae of Liang (2000), presented by Eq. (1) and (2), are used to compute MODIS and TM total shortwave broadband albedo (0.25-2.5µm) from its spectral albedos. Assuming Lambertian surfaces, surface inherent narrowband albedos are equal to bidirectional spectral surface reflectances received from atmospherically corrected satellite observations.

MODIS:
$$\alpha_{short} = 0.16\alpha_1 + 0.291\alpha_2 + 0.243\alpha_3 + 0.166\alpha_4 + 0.122\alpha_5 + 0.081\alpha_7 - 0.0015$$

$$(1)$$

TM:
$$\alpha_{short} = 0.356\alpha_1 + 0.13\alpha_3 + 0.373\alpha_4 + 0.085\alpha_5 + 0.072\alpha_7 - 0.0018$$

where α_{short} = total shortwave albedo (0.25-2.25µm)
       α_i = spectral albedo from spectral band i

Simulated Data

To avoid effects caused by sensor-specific scan geometries, "ideal" data have been simulated from the HyMap dataset. Due to the nearly continuously spectral coverage of the complete VIS/NIR/SWIR-region with narrow bands, the hyperspectral dataset is appropriate to generate both synthetic MODIS and TM data as a weighted combination of HyMap bands. This was achieved by integrating the relevant HyMap bands according to the spectral response function of each MODIS and TM band (Figure 5). Finally, each channel of MODIS and TM was represented as a linear combination of specifically weighted HyMap bands (Figure 2).

Besides the simulation of the spectral characteristics, an additional processing step was necessary to account for the spatial characteristics of both instruments. For this purpose, the Point Spread Function (PSF) of the scanning system was applied. Every image collected by an instrument onboard a satellite or aircraft platform is affected by current atmospheric conditions, blurring caused by the instrument´s optics, detectors and electronics and platform motion. These influences lead to an image with low contrasts and loss of details (Kavzoglu, 2004). This degradation can be described by the PSF, which has the approximate shape of a Gaussian function in both scan- and track-direction (Huang et al., 2002; Townshend et al., 2000). To fulfill a realistic spatial simulation of the MODIS and TM data based on HyMap, each band was convolved with the according sensor PSF and afterwards aggregated to the pixel size of MODIS (463m) and TM (30m), respectively. This step was

followed by the calculation of the broadband shortwave albedos from the generated reflectance data. In order to avoid confusion the terms MODIS$_{sim}$ and TM$_{sim}$ will be used in the following to define the data that resulted from the spectral and spatial processing described above.

Real Data

From the MODIS scenes, subsets were defined to cover the relatively small study area. The "MODIS reprojection tool" (MRT) was used to trim the data to the desirable extent and to adapt the geodetic projection systems.

To allow a quantitative comparison of the albedo values received from MODIS and TM, a systematic degradation of the TM data was performed (Justice et al., 1989; Kavzoglu, 2004) using the PSF of MODIS (derived from a series of prelaunch measurements at system level; Barnes et al., 1998).

The normalized PSF of each MODIS band was applied to the corresponding TM band. As a final degradation step, TM data were aggregated to a pixel size of 463m, which corresponds to the MOD09 product. In the following, broadband albedos calculated from MOD09 and the aggregated TM data (TM$_{agg}$) were compared for all acquisition dates.
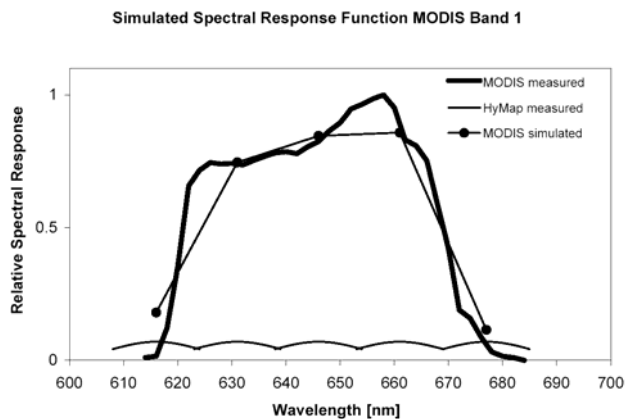

Figure 2. Example of using HyMap data to generate ideal MODIS data: HyMap channels 13 - 17 (Gaussian response functions) were weighted according to the MODIS spectral response function to generate MODIS band 1

4. RESULTS & DISCUSSION

Simulated Data

The comparison of albedos derived from MODIS$_{sim}$ and TM$_{sim}$ showed an almost perfect linear relationship (Figure 3). Values scattered marginally around the 1:1-line at the highest range of values, but in total, deviations from the 1:1-line were negligible. Pearson's r was 0.996, and the root mean squared deviation (RMSD) equalled 0.006 (Figure 3). The conversion formulae have been provided by Liang (2000) to cover a wide range of natural surface types. The almost perfect match between both datasets found here verified these formulae that obviously can be applied consistently for surface characteristics found in the central European study region with a hetero-geneous mixture of different cover types in one pixel. This again suggests that a linear mixing principle is valid for heterogeneous (mixed) surface types (Liang et al., 2002). As the results of the applied processing scheme to degrade TM data to broad MODIS-like pixels were consistent, this approach was applied without modification to the real TM data.
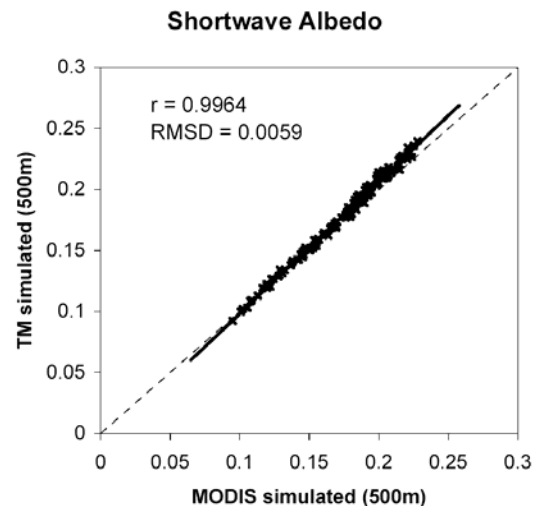

Figure 3. Comparison of shortwave albedo derived from MODIS$_{sim}$ and from TM$_{sim}$ after aggregation

Real Data

For the real data acquired at 28 May 2005, the albedos retrieved from the degraded and aggregated TM data correlated highly with those from the MOD09 product (Pearson´s r = 0.88) and grouped around the 1:1-line (Figure 4), although viewing geometries differed significantly between both sensors (see Figure 1 for MODIS, TM with near-nadir viewing geometry). Daily albedos (MOD09) were also highly correlated with the 16-day composite, but with an offset of about 0.03 (MOD09 > MCD43A3). Different from MOD09 and TM data, MCD43A3 reproduces the 16-day average condition. It also encloses a correction of the surface BRDF effects.
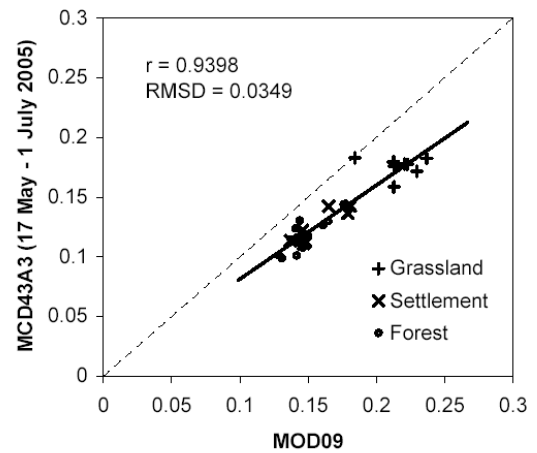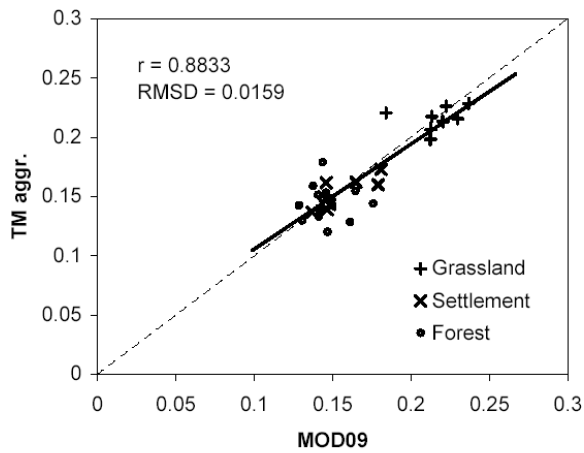
Results were different for 19 July and 4 August 2003. Again, linear relations between albedos from MOD09 and TM$_{agg}$ were found, r equalled 0.94 and 0.86, respectively, but at both dates albedos from TM$_{agg}$ had a clear offset towards MOD09 results (TM$_{agg}$ > MOD09). One explanation for these results differing from 2005 might be, that effects from BRDF changed distinctly from July/August to May (mainly due to phenology). As for example coniferous forests with relatively small phenological variations were also included in the analysis, this yields not a full explanation. MOD09 and MCD43A3 showed a very good match at both dates in 2003 with low deviations around the 1:1-line (19 July 2003: r = 0.9751; 4 August 2003: r = 0.9121). The mismatch between TM albedos and MCD43A3 is not in line with the findings of Liang et al. (2002), who stated a very good agreement of total shortwave albedos retrieved from these data. Nevertheless, Fang et al. (2004) also found some moderate mimatches between albedos obtained from MODIS and Landsat ETM+. For these deviations, uncertainties associated with the atmospheric corrections (water vapor content and aerosol corrections) may provide some explanation (Liang et al., 2002).
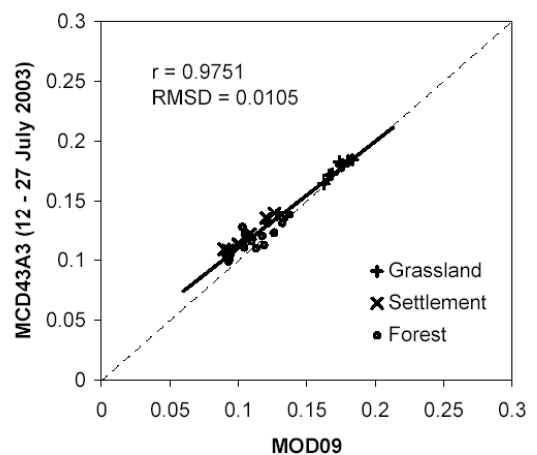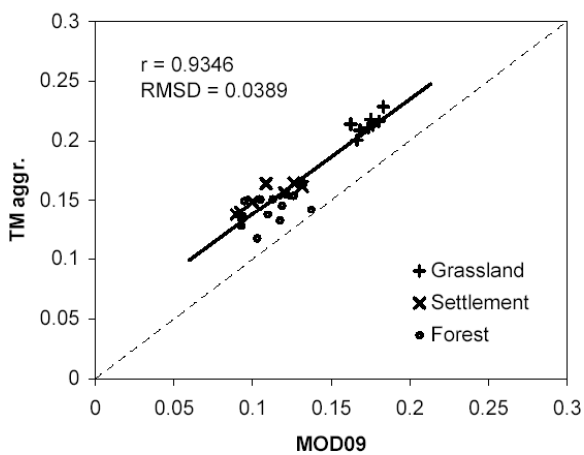
5. CONCLUSIONS

From our findings, the following main two conclusions may be drawn:
– The formulae of Liang (2000) to calculate land surface broadband albedos from TM and MODIS data were successfully applied to specifically degraded HyMap data. Conversion formulae were suitable for mixed surfaces of different land cover types.

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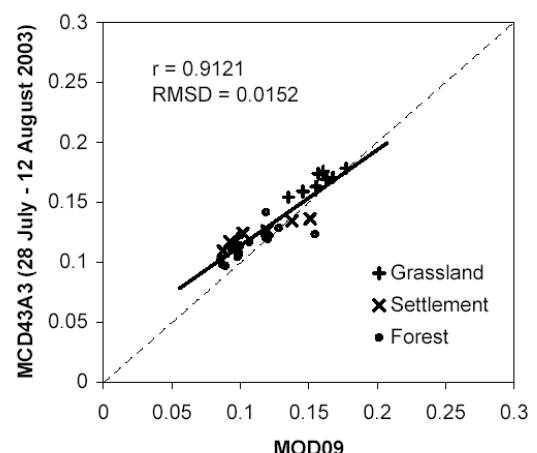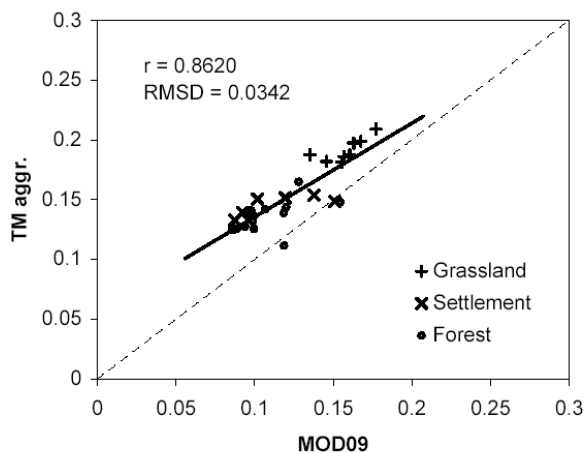Contents   Author Index   Keyword Index

Figure 4 Comparison of albedos calculated from MOD09 with retrievals from smeared and aggregated TM data (left column) and albedos from the MODIS albedo product MCD43A3 (right column)
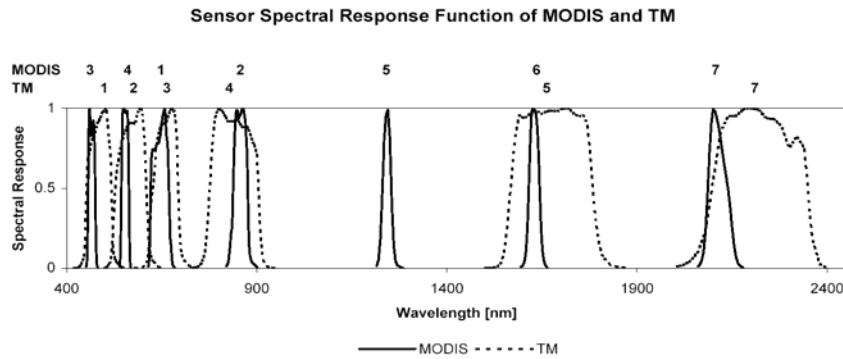
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Figure 5. Relative spectral response functions of MODIS and TM

– Albedo retrievals from the different data and products were highly correlated (0.98 ≥ r ≥ 0.86). The reason why data showed (moderate) offsets was not fully understood from the processing schemes associated with the different datasets.

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