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Spectral surface reflectance determination from multi-spectral MODIS satellite data in the frame of INDALO 2003

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Summary

This paper presents the results of the determination of spectral surface reflectance from multi-spectral MODIS data obtained during the field campaign INDALO2003, developed at the Tabernas Desert in South Eastern Spain. This field campaign has been developed to obtain experimental data on the atmospheric aerosol properties. For this purpose a set of instruments has been operated at the Solar Power Plant of Almería, since 15 till 26 September 2003, in order to characterize the physical and chemical composition of the atmospheric aerosol, both by using remote sensing and in situ techniques. Direct measurements of the surface spectral albedo and spectral bidirectional reflectance have been achieved by using a field spectroradiometer. These measurements in combination with the aerosol optical depth measured by a CIMEL 318 radiometer has been used as ground truth for the determination of spectral surface reflectance from MODIS satellite data.

1. Introduction

INDALO2003 (F**I**eld campaig**N** for **D**etermining **A**tmospheric aeroso**L** pr**O**perties in semiarid regions), developed at the Tabernas Desert in South Eastern Spain during the month of September 2003, has been the result of the coordinated activities of the Universities of Granada (Spain), Vienna (Austria), Basilicata (Italy), IMAA-CNR (Italy), Institute of Earth Sciences-CSIC (Spain) and CIEMAT (Spain). This field campaign has been developed to obtain experimental data on the atmospheric aerosol properties. The selected area is a semiarid region in Southeastern Spain above 50 km away from the Mediterranean Sea and certainly close to North Africa. Due to the flat conditions of the area and the fact that during some days of the campaign rather "clean" conditions (no clouds and very low aerosol content) were observed the surface reflectance was determined for a homogeneous area in four different spectral regions (620 – 670 nm; 841 – 976 nm; 459 – 479 nm and 545 – 565 nm) and for different spatial resolutions (1 × 1 km^2, 500 × 500 m^2 and 250 × 250 m^2 at the nadir), using MODIS data.

2. Data.

MODIS is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra's orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth's surface, acquiring data in 36 spectral bands. The MODIS instrument provides high radiometric sensitivity in 36 spectral bands ranging in wavelength from approximately 0.4 to 14.4 µm. Two bands are imaged at a nominal resolution of 250 m (620-670nm; 841-876 nm) at nadir, five bands at 500 m (459-479nm; 545-565nm; 1230-1250nm; 1628-1652nm; 2105-2155nm) and the remaining 29 bands at 1000 m. A ±55° scanning pattern at the EOS orbit of 705 km achieves a 2330 km swath and provides global coverage every one to two days.

Measurements of the surface spectral albedo and spectral bidirectional reflectance in the UV-VIS_NIR range have been achieved by using a field spectroradiometer LICOR-1800. This is a single monocromator spectroradiometer that provides spectra in the range 300-1100 nm with a FWHM of 6 nm. The instrument was calibrated with 200 W tungsten lamp referenced to a primary standard provided by the U.S. National Bureau of Standards (NBS). The measurements have been done in 10 nm steps from 350 y 1100 nm. For the albedo measurements we have used a remote cosine response head, while for the reflectance measurements we used a telescope with 15º IFOV. Both input optics were connected to the spectroradiometer by means of an optical fibre. As reference lambertian surface a Spectralon plate was used. All the measurements were done under cloudless conditions. The target surface was representative of the sparsely covered landscape.

A CIMEL radiometer was used to obtain solar transmission measurements at 340, 380, 440, 670, 870, 940 and 1020. The measured aerosol optical depth was derived from the total optical depth subtracting the Rayleigh optical depth and O_3 and NO_2 absorption optical depths and using the appropriate calibration constant, which was obtained from the Langley plots at high location in Sierra Nevada range (2200m msl) and Lamp calibrations. The uncertainty in aerosol optical depth is $<\pm0.01$.

3. Methodology.

MODIS data were collected for 24th September, a typically "clean" day. The Second Simulation of the Satellite Signal in the Solar Spectrum (6S) (Vermote et al. 1997) is the radiative transfer code used to correct the satellite measured signal from the atmospheric interference. For the corrections, a standard atmospheric profile typical of mid-latitude summer and the aerosol properties measured during the Indalo-2003 campaign were considered.

Since the atmospheric correction parameters are known as well as the geometry, the model runs iteratively searching for the best match between modelled and measured radiances, varying the surface reflectance, assuming a lambertian surface. When the matching is achieved, the surface reflectance is considered retrieved. The surface reflectance is obtained in the four spectral bands mentioned before (620 – 670 nm; 841 – 976 nm; 459 – 479 nm and 545 – 565 nm) with a spatial resolution of 500×500 m^2. At the spatial resolution 250×250 m^2 the reflectance is determined in the first two spectral bands, since MODIS measurements with this resolution are available only in these spectral intervals. The aim of using "clean" atmospheric days is the reduction to a minimum of the impact that the atmospheric corrections (due to aerosols) may have of the retrievals, since they are essential for surface studies from satellite data. Gaseous absorption errors are reduced to a minimum since no important absorption bands are present in the spectral regions used for the reflectance retrieval.

The MODIS Land Surface Science Team makes available an operational Land Surface product (Vermote and Vermeulen 1999) through the Goddard Distributed Active Archive Center – DAAC. The product contains amongst other the land surface reflectance for several spectral bands and spatial resolutions (500×500 m^2 and 250×250 m^2), also retrieved from the present method. Results from MODIS Reflectance product are presented in Table 2.

4. Results.

The next figures show the surface reflectance values obtained in the spectral bands used. The area considered for these determinations is located in the South of Spain, centred in the following geographical coordinates: Latitude 37.09º, Longitude -2.36º. Figures 1 and 2 respect the same spectral region but differ from the spatial resolution (250×250 m^2 and 500×500 m^2, respectively). It can be observed that this difference results in a better definition of the surface patterns in the image of Figure 1 (spatial resolution: 250×250 m^2), while in Figure 2 (spatial resolution: 500×500 m^2) some discontinuities may be observed. Figure 3 presents the results with 500x500 m^2 resolution for the wavebands centred at 470 and 555 nm.

The black dots in the maps represent the location where the ground-based measurements were done (Lat: 37.09º, Long: -2.36º) and the grey dots represent the nearest pixel of the MODIS satellite image taken for comparison. The highest reflectance values observed in some parts of the maps are probably connected with the occurrence of clouds in that area.

Time UTC	**Area**	**S. Resolution**	**Surface Reflectance**			
			470 nm	**555 nm**	**650 nm**	**860 nm**
1020	A	500×500 m^2	0.139	0.158	0.182	0.227
	NP		0.132	0.144	0.161	0.198
1335	A		0.109	0.136	0.161	0.197
	NP		0.107	0.131	0.155	0.186
1020	A	250×250 m^2	-	-	0.184	0.226
	NP		-	-	0.199	0.231
1335	A		-	-	0.160	0.196
	NP		-	-	0.139	0.168

Table 1 – Results obtained for the lambertian surface reflectance applying the methodology described to MODIS satellite images.

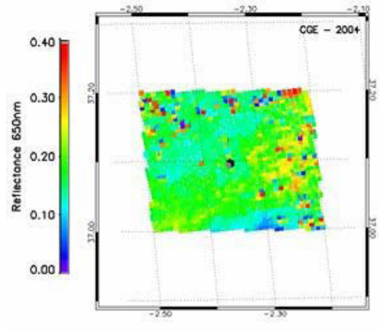

Figure 1a: *Surface reflectance from MODIS, 24 September 2003, 1335 UTC. Spatial resolution 250 × 250 m² and spectral region 620 - 670 nm.*

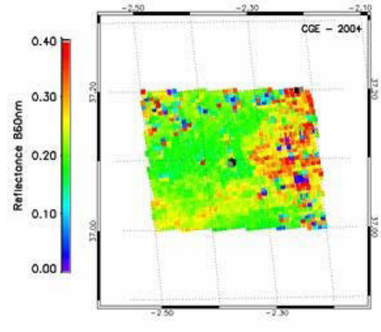

Figure 1b: *Surface reflectance from MODIS, 24 September 2003, 1335 UTC. Spatial resolution 250 × 250 m² and spectral region 841 – 876 nm.*

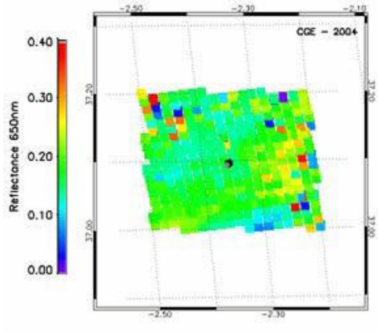

Figure 2a: *Same as Figure 1a with spatial resolution 500 × 500 m².*

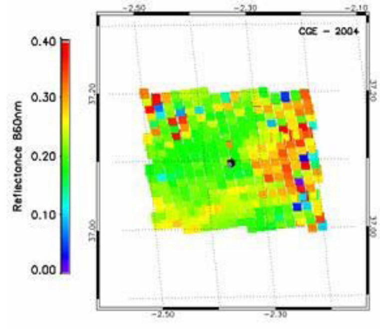

Figure 2b *Same as Figure 1b with spatial resolution 500 × 500 m².*

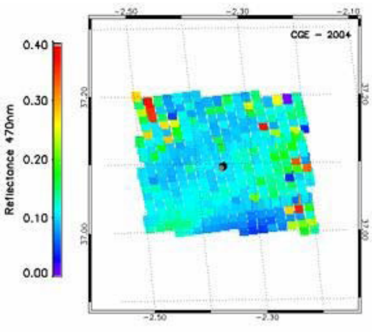

Figure 3a: *Same as Figure 1a with spatial resolution 500 × 500 m² and spectral region 459 - 479 nm.*

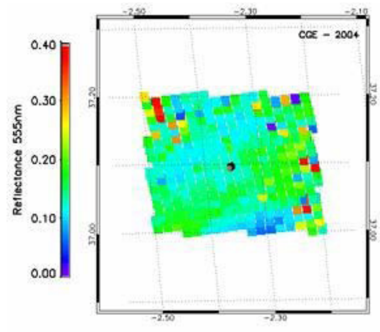

Figure 3b: *Same as Figure 1a with spatial resolution 500 × 500 m² and spectral region 545 - 565 nm.*

The results obtained for the lambertian surface reflectance derived from MODIS satellite measurements are summarised in Table 1. Results presented respect the nearest pixel to the point where the ground-based measurements were done**,** NP, as well as the average obtained for the pixels contained in the area of 0.025º × 0.025º centred in the point where the ground-based measurements were taken, A. A comparison with the MODIS surface reflectance product for the same day shows that we obtained greater surface reflectance for 650 and 680 nm, while the opposite applies to 470 and 550 nm, Table 2.

Time UTC	Area	S. Resolution	Surface Reflectance 470 nm	555 nm	650 nm	860 nm
1020	A	$500 \times 500\ m^2$	0.112	0.151	0.197	0.243
	NP		0.118	0.157	0.202	0.259
1335	A					
	NP					
1020	A	$250 \times 250\ m^2$	-	-	0.196	0.243
	NP		-	-	0.205	0.273
1335	A					
	NP					

Table 2 – Surface reflectance obtained from the MODIS surface reflectance product.

The comparisons between the ground-based measurements and the satellite retrievals of the surface spectral reflectance lead to the estimation of the errors summarized in Table 3. As can be seen the nearest pixel result produces better agreement with the surface data. This could be due to the heterogeneity in our study area, where the vegetation is sparse and non-homogeneously distributed.

5. Concluding remarks.

The availability of surface reflectance measurements obtained in the frame of INDALO 2003 field campaign has been used to check a scheme for the retrieval of surface reflectance from MODIS images based on 6S code. Aerosol optical depth measured in situ has been used to perform an appropriate atmospheric correction. A rather good agreement is obtained between the reflectances measured at surface level and those retrieved from MODIS with the described method for 650 and 860 nm when the nearest pixel to the measurement point is considered. The worse results obtained with area averaged values could be a result of the heterogeneity of the surface in the study site.

Time UTC	Case	S. Resolution	Surface Reflectance error 470 nm	555 nm	650 nm	860 nm
1020	A	$500 \times 500\ m^2$	~ 35%	< 5%	~ 6%	~7.5%
1335	A		~ 36%	~ 4%	~17%	~ 25%
1020	NP	$250 \times 250\ m^2$	-	-	< 5%	5– 6%
1335	NP		-	-	< 5%	5– 6%

Table 3 – Surface reflectance relative errors between ground-based measurements and MODIS retrievals using the described methodology.

6. Ackowledgements

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7. Referencias

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