Evaluation of the correlation of the effective radius values with aerosol parameters from MODIS data

O.E. García, A.M. Díaz, F.J. Expósito, J.P. Díaz and P.A. Hernández-Leal.

University of La Laguna, Avda. Astrofísico Francisco Sánchez s/n, La Laguna 38204, Tenerife, Spain

Abstract

The aim of this work is to obtain the effective radius as a function of other aerosol retrievals from the Moderate-Resolution Imaging Spectroradiometer (MODIS) (Ångstrom parameter, aerosol optical depth, backscattering ratio,...) which can be obtained by other remote sensors like Advanced Very High Resolution Radiometer (AVHRR) with a very long time series. In order to reduce the number of MODIS useful variables a Factorial Analysis by Principal Component has been applied. With this technique we have obtained three factors, which reduce the aerosol parameters from 28 to 9. Using these 9 parameters it has been applied Lineal Multivariate Analysis techniques to find a combination of independent variables that better evaluate the aerosol effective radius. The regression model obtained explains the 99.6% of the variation in this parameter. The MODIS/Terra level-2 aerosol products over ocean has been studied for 2002-2003 in a grid centred in the Canary Islands (26ºN-31ºN, 13ºW-19ºW). It has been found that these correlations are independent of the aerosol load for any situation.

1. Introduction

To fully understand the influence of atmospheric aerosols on the radiative budget and therefore on climatic models, the aerosol characteristics (composition, size distribution and total content) have to be determined on a global scale. Among other species, the mineral dust is a significant component of tropospheric aerosols (Prospero, 1996) and it is an important radiative budget modifier, especially in those regions close to arid regions (Díaz et al., 2000).
Satellite techniques provide a very valuable information both over land and ocean to determine these aerosols characteristics. In this sense, nowadays one of the most useful tools is the MODIS instrument on board Earth Observing System *Terra/Aqua* spatial platforms, which provides a daily global coverage. This sensor is designed to perform measurements at 36 channels from visible to thermal infrared spectrum region (0.415 to 14.235µm), with a spatial resolution of 0.25, 0.50 or 1 km, depending on the band (Salomonson et at., 1989). However these platforms have been launch recently (years 2000 and 2002) so, in order to get a long time series of the aerosol characteristics, it would be desirable to obtain these parameters as a function of other aerosol retrievals which could be obtained by other space platforms launched before.
Canary Islands region is an ideal site to study the physical properties of these atmospheric constituent, since it is very close to one of the major source areas for mineral dust: the Sahara and Sahel regions of North Africa. Thus Díaz et al. (2004) show that the air masses which transport mineral dust from the African continent to the Izaña GAW station, located in the free troposphere in the Canary Islands, has an annual frequency of 20%.

2. Effective Radius Distribution

The MODIS retrieval algorithm over ocean has been validated under different conditions. In non-dust regimes over ocean Remer et al. (2002) has shown that the aerosol effective radius is

retrieved to within ±0.10 μm. Considering this accuracy as bin, we have calculated the frequency distribution of the effective radius for 2002 and 2003 within our study area.
On the other hand, in dust conditions the retrieved size parameters can systematically underestimate actual aerosol size. These differences can be explained in part by the assumption of the dust as spherical particles in the MODIS retrieval algorithm (Levy et al., 2003).
In general, the effective radius is mainly presented in the ranges 0.60 – 0.70 and 1.90 – 2.00 μm bin, representing a bimodal distribution for both years. Also, it appears a third peak for 1.40 – 1.50 μm bin, which can be observed clearest if we consider the frequency distribution for seasons (Fig. 2). As Levy et al. (2003) show in his work, the effective radius of 1.98 μm is associated with wet sea-salt aerosol, 2.50 μm with dust-like aerosol and 1.48 μm with both. Thus we can associate these peaks with the presence of these atmospheric compounds, which are the main sources of aerosols for coarse mode in our region.
The number of pixels during the cold season (winter-autumn) is higher than in the warm one (spring-summer) for both years, due to the presence of more cloudy days in these months. For the cold season the frequency distributions are slightly broader than in the warm one having median values of effective radius higher. However this difference is within the accuracy obtained by Remer et al. (2002). This is shown in the Table 1, which summarises the statistics parameters for the frequency distribution of the effective radius.

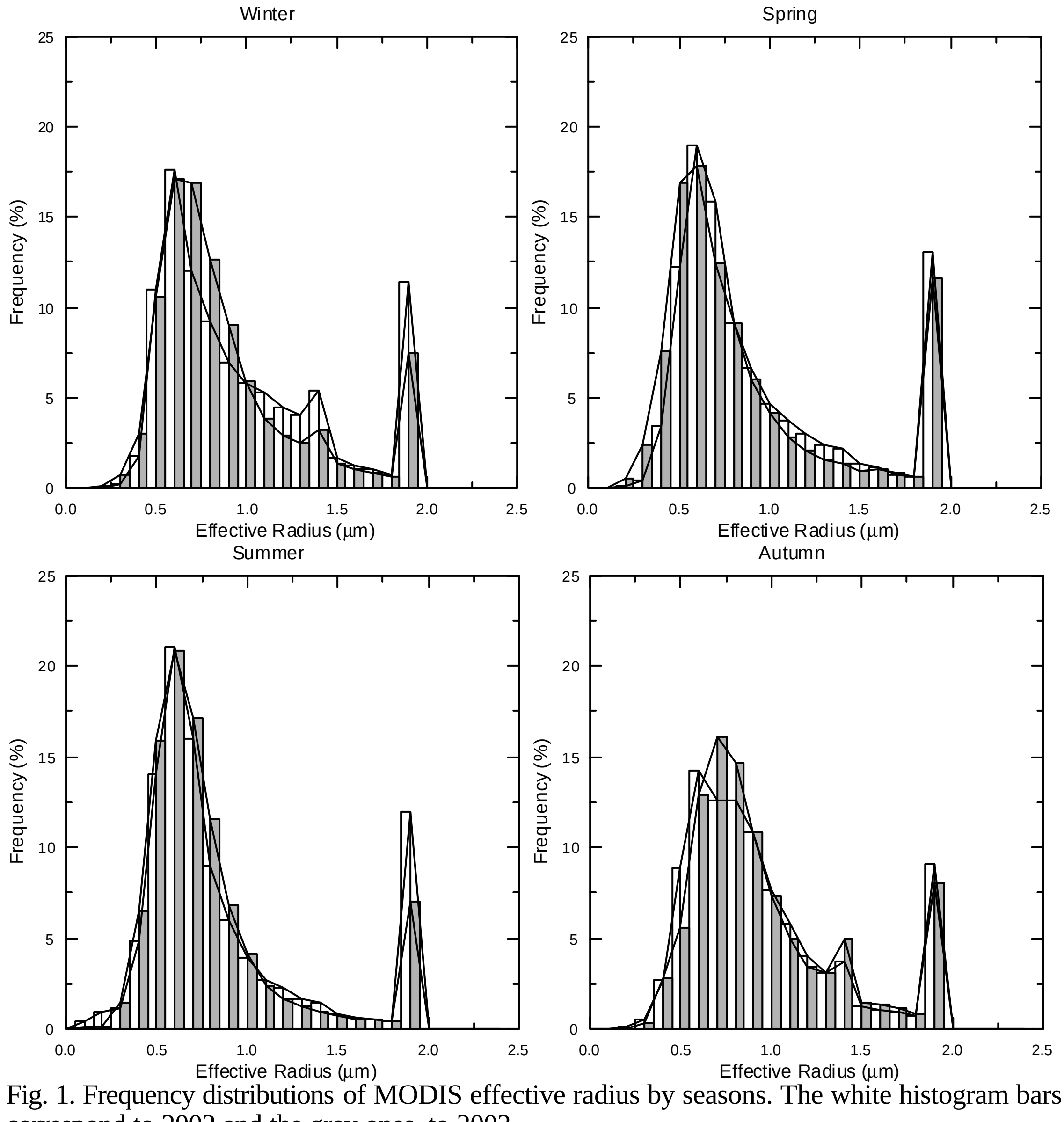

Fig. 1. Frequency distributions of MODIS effective radius by seasons. The white histogram bars correspond to 2002 and the grey ones, to 2003.

Table 1. Measures of central tendency (mean and median), dispersion (standard deviation) and distribution (skewness) for the frequency distribution of effective radius.

	Winter		Spring		Summer		Autumn		All	
	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Pixels	85603	59525	27774	28818	37599	41713	73123	48674	224099	178730
Median	0.87	0.81	0.79	0.73	0.74	0.73	0.88	0.88	0.84	0.80
Stnd. Dev.	0.46	0.41	0.47	0.48	0.47	0.39	0.42	0.41	0.45	0.42
Mean	1.03	0.94	0.98	0.91	0.92	0.85	1.00	1.01	1.00	0.93
Skewness	0.88	1.28	1.09	1.24	1.28	1.73	1.05	1.08	1.02	1.28
Skewness SD	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01

3. Factorial Analysis

From factorial analysis it has extracted three factors or principal components for both years, using the Kaiser criterion (i.e. eigenvalues higher than one). The total explained variance from the original data set, which is obtained with these three factors, is about 92% for 2002 and 2003. Also, the final communality is higher than 80% for all MODIS variables, except for the cloud fraction. In particular, for the effective radius is around 91% for both years.

The association of each MODIS variable with its factor improves if a rotation of the principal components is applied. So, the Table 2 shows the component matrix for a Varimax rotation of the three factors: all original MODIS variables and the factors, which are included. Note the correlation coefficients are higher than 0.80 for all variables and in particular, as the effective radius is associated with the Ångstrom parameter, the backscattering ratio and the asymmetry factor in the factor 2.

Table 2. Component matrix for two years.

Factor 1			**Factor 2**		
	2002	2003		2002	2003
MR3[a]	0.87	0.84	**ER2[f]**	**-0.94**	**-0.94**
MR4	0.94	0.92	AE[g]	0.87	0.87
TF3[b]	-0.83	-0.77	BR1[h]	0.98	0.98
TF4	-0.87	-0.83	BR2	0.98	0.99
EOD1[c]	0.98	0.975	BR3	0.98	0.98
EOD2	0.98	0.98	BR4	0.95	0.95
EOD3	0.98	0.98	AF1[i]	-0.96	-0.96
EOD4	0.98	0.98	AF2	-0.97	-0.97
ODL1[d]	0.97	0.96	AF3	-0.97	-0.97
ODL2	0.97	0.96	AF4	-0.95	-0.96
ODL3	0.97	0.96			
ODL4	0.97	0.96	**Factor 3**		
ODS1[e]	0.94	0.92		2002	2003
ODS2	0.94	0.92	RF3[j]	0.85	0.87
ODS3	0.94	0.92	RF4	0.82	0.85
ODS4	0.93	0.92			

a.Mean Reflectance b.Transmitted Flux c.Effective Optical Depth d.Optical Depth Large e.Optical Depth Small f.Effective Radius g.Ångstrom Exponent h.Backscattering Ratio i.Asymmetry Factor j.Reflected Flux.
The number is the MODIS channel.

4. Lineal Multivariate Analysis

With the MODIS variables obtained from factorial analysis (Factor 2), a lineal multivariate fit of the effective radius for the two years has been computed (Table 3). For both cases, it has been obtained a very high determination coefficient, around 0.99. Note the small difference for the fit coefficients between 2002-2003, especially for the first four values, which have the highest weigh in the fit (99%).

Table 3. Fit coefficients and its standard deviation, which are sorted by its weight in the fit

	2002	2003
	Coefficient ± SD	Coefficient ± SD
Constant	32.39 ± 0.03	31.17 ± 0.03
BR1	-54.79 ± 0.13	-53.30 ± 0.14
AF2	-30.76 ± 0.13	-28.02 ± 0.15
AE	0.59 ± 0.00	0.58 ± 0.00
BR4	-0.49 ± 0.11	-2.04 ± 0.12
AF4	7.18 ± 0.06	8.53 ± 0.07
AF3	-5.93 ± 0.12	-9.58 ± 0.13
BR2	-11.36 ± 0.16	-11.12 ± 0.17
AF1	4.64 ± 0.09	5.47 ± 0.10
BR3	-6.10 ± 0.17	-4.76 ± 0.18

The backscattering ratio at 0.47 μm and the asymmetry factor at 0.55 μm are the variables that have more weight in the regression model, explaining the 98% of the variation in the effective radius. If only these variables are considered in the multivariate analysis, the linear fits are:

$$ER2 = -49.16\,BR1 - 17.06\,AF2 + 22.39 \quad \text{for 2002} \qquad (1)$$

$$ER2 = -48.36\,BR1 - 16.61\,AF2 + 21.92 \quad \text{for 2003} \qquad (2)$$

5. Residual Analysis

In order to estimate the residues from the regression model, we have evaluated the effective radius for 2003 with the lineal multivariate fit obtained for 2002 (Eq. (1)), which is shown in the Figure 2.

As it is shown in the Figure 3, the main scatter is observed for effective radius higher than 2.00 μm (Range B) and smaller or equal than 0.25 μm (Range A). Nevertheless for 2003 the percentage of cases for range 1 is 0.077% (138 cases), whereas for range 2 is 0.001% (17 cases). If we considered the two main errors sources in the remote sensing retrieval algorithms, i.e., the presence of clouds and aerosols load, it is observed as the residues are independent as much of the cloud fraction as of the effective optical depth (EOD2), but not of the BR1 and AF2. In both cases these errors are associated with small effective radius.

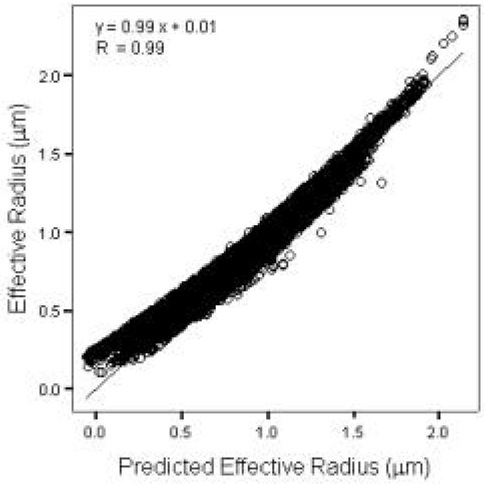

Figure 2. Experimental versus predicted effective radius.

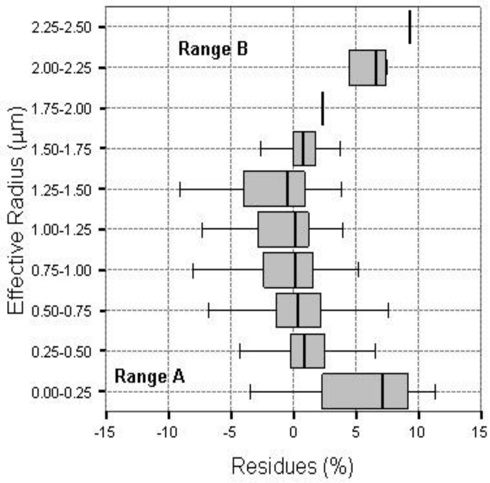

Figure 3. Estimated residues from the regression model.

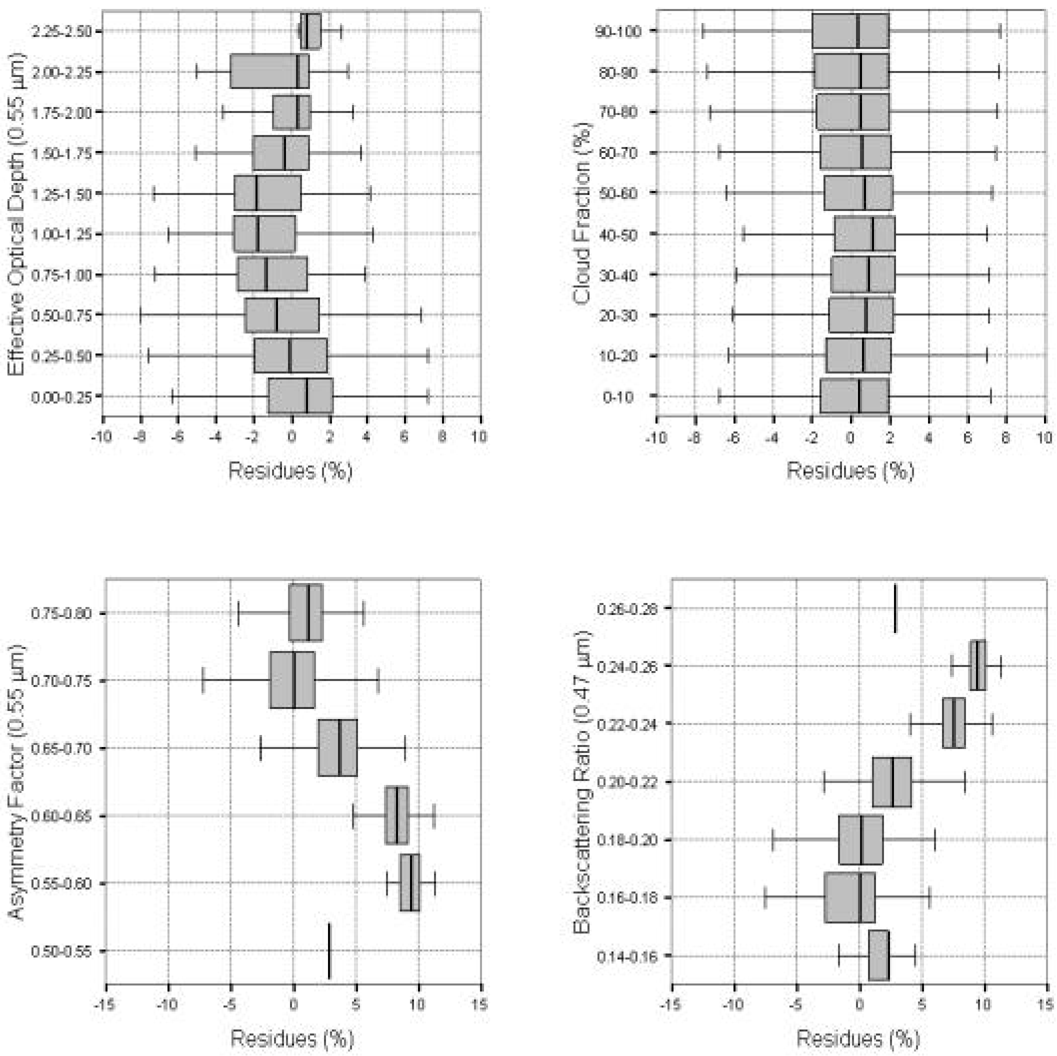

Figure 4. Estimated residues versus Cloud Fraction, EOD2, BR1 and AF2.

6. Conclusions

The effective radius tries to characterize the aerosol size distribution with one parameter, giving an estimation of particle size. In this work an alternative methodology to evaluate this aerosol parameter, when the size distribution is unknown or can not be obtained, has been proposed. The frequency distribution of the effective radius over our study region (grid around Canary Islands) shows a bimodal distribution, however a third peaks only appears for the cold season (winter-autumn). This peak is associated with the presence of maritime aerosols and mineral dust, since these aerosols are the dominant species in our region.
To all MODIS variables obtained during 2002 and 2003, it has been applied a factorial analysis, extracting three factors. These principal components explain around 92% of the variance of the original data, being the final communality as minimum of 80% for all MODIS aerosol parameters. With this previous analysis it has been reduced the number of MODIS parameters to evaluate the effective radius. So, to compute the multivariate fit, only nine variables have been considered, which explain the 99.6% of the effective radius variation. Also, it has found that only two variables (backscattering ratio at 0.47 μm and the asymmetry factor at 0.55 μm) reproduce this parameter in a 98%.
Finally to validate the obtained multivariate fit with two variables, the residues of the regression model under a variety of conditions have been studied. It has obtained that this fit is valid under any cloud fraction and aerosol load, but it is not independent neither the backscattering ratio nor asymmetry factor. The major errors are associated with the smaller effective radius.

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7. References

Díaz, A.M, Díaz J.P. Expósito F.J., et al. Air masses and aerosols chemical components in the free troposphere at the Subtropical Northeast Atlantic region, in preparation, 2004.
Díaz, J.P., Expósito, F.J., Torres, C.J., et al. A simulations of mineral dust effect on UV radiation levels. J. Geophys. Res., 105 (4), 4979-4992, 2000.
Levy, R.C., Remer L.A., Tanré D.,et al. Evaluation of the MODIS retrievals of dust aerosol over the ocean during PRIDE. J. Geophys. Res., 108 (19), 8594-8607, 2003.
Prospero, J.M. Saharan dust transport over the North Atlantic ocean an Mediterranean: And overview, in: Guerzoni, S. and Chester R. (Eds.), The Impact of Desert Dust Across the Mediterranean, Kluwer Acad., Norwell, Mass., pp.133-151, 1996.
Remer, L.A., Tanré D., Kaufman Y.J., et al.Validation of MODIS aerosol retrieval over ocean. Geophys. Res. Lett., 29 (12), 1-4, 2002.
Salomonson, V.V., Barnes W.L., Maymon P.W., et al. MODIS: Advanced facility instrument for studies of the Earth as a system, IEEE Trans. Geosci. Remote Sens., 27,145-153,1989.