Atmos. Chem. Phys. Discuss., 8, 16891–16916, 2008
www.atmos-chem-phys-discuss.net/8/16891/2008/

Atmospheric Chemistry and Physics Discussions

This discussion paper is/has been under review for the journal *Atmospheric Chemistry and Physics (ACP)*. Please refer to the corresponding final paper in *ACP* if available.

Assessment of the MODIS Collections C005 and C004 aerosol optical depth products over the Mediterranean basin

C. D. Papadimas[1,2], N. Hatzianastassiou[1,2], N. Mihalopoulos[3], M. Kanakidou[3], B. D. Katsoulis[1], and I. Vardavas[2,4]

[1]Laboratory of Meteorology, Department of Physics, University of Ioannina, Ioannina, Greece
[2]Foundation for Research and Technology-Hellas, Heraklion, Crete, Greece
[3]Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, Heraklion, Crete, Greece
[4]Department of Physics, University of Crete, Heraklion, Crete, Greece

Received: 3 June 2008 – Accepted: 12 August 2008 – Published: 9 September 2008

Correspondence to: N. Hatzianastassiou (nhatzian@cc.uoi.gr)

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

Abstract

The second generation Collection 005 (C005) MODIS operational algorithm for retrieval of aerosol properties was evaluated and validated for the greater Mediterranean basin (29.5° N–46.5° N and 10.5° W–38.5° E), a region with an atmosphere under siege by air pollution and diminishing water resources that are exacerbated by high aerosol loads and climatic change. The present study aims to quantify the differences between the C005 and the previous (C004) MODIS collections, and re-assess the results of previous studies that have been performed for the region using MODIS C004 aerosol optical depth (AOD) products. Daily data of AOD from EOS-Terra covering the 6-year period 2000–2006 were taken from both C005 and C004 Level-3 datasets, and were inter-compared and validated against ground-based measurements from 29 AERONET stations. The C005 data were found to significantly better agree with the AERONET data than those of C004. The correlation coefficient between MODIS and AERONET was found to increase from 0.66 to 0.76 and the slope of linear regression MODIS/AERONET from 0.79 to 0.85. The MODIS C005 data still overestimate/underestimate the AERONET AOD values smaller/larger than 0.25, but to a much smaller extent than C004 data. The better agreement of C005 with AERONET data arises from the generally lower C005 values, with regional mean AOD values equal to 0.27 and 0.22 for C004 and C005, respectively. This decrease, however, is not uniform over the region and involves a significant decrease over land and a small increase over the ocean for AOD values greater than 0.1 (opposite changes were found under aerosol-clean conditions). Both data sets indicate a decrease in the regional mean AOD over the period 2000–2006, equal to 20% based on C005 and 17% based on C004 datasets, though the intra-annual and inter-annual variation did not change significantly, thus indicating a systematic correction to C004 values.

1 Introduction

Aerosols are very important to the Earth's climate playing a crucial role in the radiation budget, cloud processes and air quality. Changes in the atmospheric aerosol load, as well as changes, for example, in greenhouse gases, solar radiation and land surface properties, alter the energy balance of the Earth-atmosphere climate system. These changes are usually expressed in terms of associated radiative forcings on the global climate. Aerosol forcing remains the dominant uncertainty in climate radiative forcing (IPCC, 2007) mainly due to the incomplete knowledge of aerosol physical, and chemical properties, and to the short atmospheric aerosol lifetime. Therefore, continuous monitoring of aerosol properties is of high priority since it significantly contributes in constructing a concise picture of aerosols. This monitoring is currently being performed via globally distributed ground-based station networks (mainly Aerosol Robotic Network, AERONET, Holben et al., 2001) which have however incomplete spatial coverage, and by satellites that measure several aerosol properties on a planetary scale and at high spatial resolution. Satellite data, in conjunction with radiative transfer models, are invaluable for monitoring the global aerosol budget and the aerosol radiative effects on climate (Charlson, 1992; Penner et al., 1992; Kaufman et al., 2002; Vardavas and Taylor, 2007).

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the Terra and Aqua satellites is retrieving daily global aerosol products over land and ocean in a variety of spectral bands from blue to thermal infra-red (Kaufman et al., 1997; Remer et al., 2005) every 1–2 days with a 16-day repeat cycle. Terra and Aqua (both with a 705 km orbit) are in a sun-synchronous, near polar, circular orbit. Aqua crosses the equator daily at 01:30 p.m. LT as it moves north (ascending mode) in contrast to Terra, which crosses the equator at 10:30 a.m. daily (descending mode). Since its first launch (18 December 1999), the MODIS aerosol algorithm has been continuously updated and evaluated by the MODIS scientific team. This resulted in a complete set of products, called Collection 004 (C004), that are based on MODIS algorithm version

ACPD

8, 16891–16916, 2008

V4.2.2 (Kaufman et al., 1997; Tanre at al., 1997; Levy et al. 2003; Remer et al., 2005). To date, many studies (e.g. Remer et al., 2001; Chu et al., 2002; Ichoku et al., 2002; Remer et al., 2002; Vermote et al., 2002; Xia et al., 2004; Levy et al., 2005; Remer et al., 2005) have been carried out validating the MODIS aerosol products against those retrieved from ground-based sun photometer observations, mainly those of AERONET. Most of these validation studies have shown that although MODIS aerosol optical depth (AOD) values were within the expected error, the lower AOD values were overestimated and the higher AOD values were underestimated (Chu et al., 2002; Remer et al., 2005; Levy et al., 2005). Specifically over bright surfaces and dust regions, a number of studies (Kaufman et al., 2000; Chin et al., 2004; Tripathi et al., 2005; Jethva et al., 2007; Santese et al., 2007a) have shown that mainly because of spatial heterogeneity and higher uncertainty associated with the surface reflectance, the MODIS C004 AOD tended to be overestimated compared to ground-based observations.

The systematic biases of the MODIS C004 algorithm, mainly over land, led the MODIS team to improve the retrieval algorithm. The new version V5.2 of the MODIS algorithm, called Collection 005 (C005), was implemented recently (Levy et al., 2007a, b) to correct systematic biases of the earlier used MODIS algorithm C004. The complete description of the new second-generation algorithm and its major changes with respect to the previous one can be found in the "Algorithm Theoretical Basis Document for Collection 5" (ATBD-2006; available at: http://modis-atmos.gsfc.nasa.gov/MOD04_L2/index.html) and in other works (Levy et al., 2007a, b).

In the present study, we evaluate the differences between the six-year (2000–2006) MODIS Terra C005 and C004 AOD daily products at 550 nm (AOD_{550}) retrieved by these two algorithms. The evaluation is of great interest to document the differences between the two MODIS collections, and re-assess the results of previous studies (Barnaba and Gobbi, 2004; Ichoku et al., 2005; Levin et al., 2005; Meloni et al., 2006; Kazadzis et al., 2007; Kaskaoutis et al., 2007; Santese et al., 2007a, b) that have been performed for the region using MODIS C004 AOD products. The evaluation is performed at the geographical cell ($1^\circ \times 1^\circ$ latitude-longitude) level over the greater

Mediterranean basin. This region is of particular importance because it is a crossroad where aerosols from different sources are superimposed and mixtures of different kinds of particles converge (e.g. Lelieveld et al., 2002) such as fine anthropogenic aerosols from Europe, desert dust from North Africa and maritime aerosols from the Mediterranean Sea. In addition, in the Mediterranean basin aerosols exert a strong climatic effect especially in summer, due to the cloud-free conditions and high solar radiation intensity. The evaluation of the two datasets is performed through comparison of both the reprocessed MODIS C005 and the previous C004 AOD at 550 nm (AOD_{550}) products against corresponding data derived from 29 AERONET stations located within the study region. In addition, the two types of MODIS AOD products are inter-compared at 900 geographical cells covering the entire study region. In the comparison, emphasis is given to differences between land and ocean areas of the Mediterranean basin.

2 Aerosol optical depth data

Global time-series of aerosol parameters have been produced from MODIS/Terra (EOS AM-1) since its launch in December 18, 1999 and from MODIS/Aqua (EOS PM-1) since 4 May 2002. The pre-launch uncertainty (theoretical error) of the MODIS aerosol optical depth (AOD) is ±0.05±0.15(AOD) over land (Chu et al., 2002) and ±0.03±0.05(AOD) over ocean (Remer et al., 2002). The spatial resolution of MODIS (pixel size at nadir) is 250 m, 500 m and 1000 m, depending on the spectral band.

The aerosol C004 and C005 datasets used in this study are part of the MODIS Terra Level-3 daily gridded atmospheric data product (MOD08_D3) available on the MODIS web site http://modis.gsfc.nasa.gov/. The data cover the broader Mediterranean basin (29.5° N–46.5° N and 10.5° W–38.5° E) for the period 1 March 2000 to 28 February 2006 (6 complete years). The MODIS Atmosphere Daily Global Product is stored on an equal angle latitude-longitude grid with a horizontal resolution of 1°×1°. Thus, 900 cells are available for each day of the 6-year study period. The present study focuses on the AOD at the wavelength of 550 nm (AOD_{550}) over land and ocean, because it is near the peak of the solar spectrum and thus associated with large radiative effects, and because AOD is usually given at this wavelength by the various available aerosol datasets. Overall, a total of 2191 daily sets of AOD_{550} data were analysed for the 900 grid points ($1^{\circ} \times 1^{\circ}$ cells) of the study region. Also, mean daily regional values were calculated for the entire study period and time series were generated.

The MODIS satellite C004 and C005 AOD_{550} data were evaluated against corresponding surface-based measurements from 29 AERONET stations in the study region. AERONET is a network of sun/sky radiometers that measure solar extinction every 15 min within the spectral range 340–1020 nm (Holben et al., 2001) used to derive total column aerosol properties (Holben et al., 1998; Dubovik and King 2000; Dubovik et al., 2000; 2002). Under cloud-free conditions, the overall uncertainty in AOD data is ± 0.01 for wavelengths greater than 440 nm and ± 0.02 for shorter wavelengths. Over the last years the AERONET network has been expanded to cover a large part of the Mediterranean basin. The 29 stations were selected based on the criteria of

i) sufficient daily AOD Level 2.0 (Quality Assured) data availability from 1 March 2000 to 28 February 2006 and

ii) complete spatial coverage of the study region.

The AERONET AOD data were compared against the average AOD data of the five MODIS $1^{\circ} \times 1^{\circ}$ latitude-longitude geographical cells surrounding each AERONET station, for each day of our 6-year study period. This provides a large number of matched data pairs and enables good statistics.

3 Aerosol optical depth comparison

Figure 1a shows the six-year (2000–2006) average spatial distribution of AOD_{550} over the broader Mediterranean basin (both land and ocean) based on daily Collection 004 MODIS data gridded in $1^{\circ} \times 1^{\circ}$ cells. High AOD_{550} values (>0.4) are found over areas with intense anthropogenic activity, like the industrial region of the Po Valley in Northern Italy and the megacity of Cairo. Large AOD_{550} values also appear over regions with significant desert aerosol loads like North Africa, southeast Spain, central Mediterranean, the Middle-East and the Anatolian plateau in central Turkey. The computed regional and annual mean value of MODIS C004 AOD_{550} for the broader Mediterranean basin is equal to 0.27±0.21, with the standard deviation showing a significant spatio-temporal variability.

Figure 1b displays the geographical distribution of absolute differences between C005 and C004 MODIS AOD_{550} data derived on a daily basis and then averaged over the entire 6-year period. In general, the differences are mostly negative indicating that the MODIS C004 mainly overestimates AOD with respect to C005 by up to 0.23. Specifically, the differences range from −0.05 to −0.23 over land surfaces, whereas along coastal areas they vary within the range of values from −0.01 to −0.05. Only over most marine locations there are small positive differences (<0.012), indicating a slight underestimation of marine AOD by MODIS C004 compared to C005. Our results indicate that the new second generation (C005) MODIS aerosol retrieval algorithm V5.2 has affected the AOD products mainly over land (Remer et al., 2006, http://modis-atmos.gsfc.nasa.gov/products_C005update.html). The correction in the algorithm mainly concerns surface reflectance, whose accurate values at three wavelengths (470, 660, 2130 nm) are used in a true inversion to which the C005 algorithm is based on. The largest differences between C004 and C005 AOD are found over land areas with large AOD_{550} values due to the influence of desert aerosols, like North Africa, south Spain, Anatolian plateau and Middle East. In these areas, the relative percentage differences (not shown here) are as high as 45%. In contrast, the differences above the northern Mediterranean Sea do not exceed −0.01 because the corrections in the new algorithm focused on improving the retrievals over land (Remer et al., 2006).

The computed annual mean AOD_{550} from MODIS C005 data for the broader Mediterranean basin equals 0.22±0.18. This value, compared to the corresponding MODIS C004 value of 0.27±0.21, indicates a 23% overestimate of AOD_{550} by C004 with respect to the C005 dataset, associated with a larger spatial variability of the C004 dataset.

In Fig. 1c we show the spatial distribution of the computed correlation coefficients (R) between daily aerosol optical depth data at 550 nm from Collection 004 (AOD_{C4}) and Collection 005 (AOD_{C5}) over the broader Mediterranean basin (both land and ocean), over the six-year (2000–2006) study period. We thus obtain temporally resolved information on possible differences between C004 and C005. Over most places of the study region, the correlation coefficients are larger than 0.85 with better agreement between the two MODIS collections (correlation coefficients >0.9) occurring over maritime than continental areas. Therefore, it appears that in general the improvement of the MODIS algorithm did not create inter-annual changes in AOD values over the region. This implies that plates like that of Fig. 1b can be used to correct, to a good approximation, the MODIS C004 AOD values regardless of the year. Nevertheless, in specific areas covering about 10% of the study region, the correlation coefficients are smaller than 0.6 and thus the year of the observations has to be considered when correcting the C004 data.

The complete spatial coverage of the Mediterranean by the MODIS allows the examination of the temporal variation of mean AODs over this region. Figure 2a depicts the six-year mean intra-annual variation of AOD_{550} for the broader Mediterranean region for both C004 and C005 and the associated standard deviations. The MODIS C004 AOD is systematically overestimated with respect to C005 throughout the year. The overestimation is larger in the warmer/drier period of the year (March to October, 12–22%) than in the colder/wetter period (November to February, 5–11%). However, the seasonal variability is not significantly changed, presenting double maxima in spring and summer, though the summer maximum is less pronounced in C005 than in C004. The spring and summer maxima are mainly associated with high desert dust loads in the eastern and central basin, respectively, transported by Mediterranean cyclones (e.g. Moulin et al., 1998). Taking this into account, the identified AOD differences between the two MODIS Collections, indicate that the previous MODIS algorithm had

ACPD
8, 16891–16916, 2008

problems mainly in areas and seasons characterized by significant aerosol dust loads, as also reported by others (Tripathi et al., 2005; Santese et al., 2007a, b).

To date, several studies (Massie et al., 2004; Streets et al., 2006; Koukouli et al., 2006; Kazadzis et al., 2007; Kishcha et al., 2007; Mishchenko et al., 2007; Papadimas et al., 2008) using either MODIS or other datasets (e.g. Total Ozone Mapping Spectrometer, TOMS or Advanced Very High Resolution Radiometer, AVHRR) reported a decreasing tendency in AOD during the last years. Tendencies derived from MODIS C004 data could be questioned because of known problems with the MODIS V4.2.2 AOD retrieval algorithm with respect to surface reflectance. Using AOD_{550} data from the C004 and C005 datasets, the time series of daily mean regional values of AOD_{550} for the broader Mediterranean region over the study period (2000–2006) for both collections have been computed and are shown in Fig. 2b. The C004 AOD_{550} over the study region reveals a decreasing tendency from 2000 to 2006 equal to −17% in relative percentage terms whilst the C005 data give −20%. There is strong covariability of the two AOD time series, with a correlation coefficient R=0.97. Therefore, it appears that the improvement of the MODIS algorithm did not affect the derived intra-annual and inter-annual variability of aerosol optical depth over the greater Mediterranean basin. In contrast, it produced a systematic correction as revealed by the almost parallel linear regression lines to C004 and C005 data.

The aerosol data from the AERONET network are considered as a reference for the assessment of the quality of satellite-derived data. Thus, the MODIS C004 and C005 satellite AOD data have been compared against data from the 29 AERONET stations (Table 1, Fig. 3a) distributed uniformly over the study region. For each station, the comparison between MODIS and AERONET is performed separately for C004 and C005 data by means of absolute differences and correlation coefficients (R_{C4-AER}, and R_{C5-AER}), whereas correlations between data from the two MODIS collections are also computed (R_{C4-C5}, Table 1). In general, there is good agreement between both C004 and C005 and AERONET AODs, since the differences (ranging from −0.08 to 0.17 for C004 and from −0.12 to 0.10 for C005) fall within the range of standard deviations of both MODIS and AERONET, ranging from 0.16 to 0.25 for C004, from 0.13 to 0.27 for C005, and from 0.08 to 0.28 for AERONET, and that MODIS is representative of geographical cells of dimensions $100\times100\,\mathrm{Km}^2$, whereas AERONET is for a specific site.

Nevertheless, better agreement with AERONET is achieved with the new MODIS algorithm V5.2, as shown by the improved statistics (higher correlation coefficient) for C005 compared to C004 datasets. Note also that locally the percentage differences with respect to AERONET AODs reach 100% for C004 against only 59% for C005.

The present analysis indicates a clear overestimation of MODIS C004 AOD data with respect to AERONET that occurs at 23 stations, against an underestimation (yellow-coloured cells in Table 1) at only 6 stations. This overestimation of AOD_{550} by MODIS C004 is especially strong at some stations characterized by desert dust, such as Nes Ziona (Israel) and Granada (Spain), where the differences are as high as 0.16 and 0.17 (relative percentage differences 64% and 100%), respectively. On the contrary, at stations characterized by anthropogenic fine aerosols (e.g. Ispra in Po Valley, Italy) the differences are small (0.05 in absolute terms or 16%). The correlation coefficients between MODIS C004 and AERONET values range from 0.40 to 0.94, with 4 stations having coefficients smaller than 0.6 (deep cyan-coloured cells) and 14 stations with coefficients smaller than 0.7 (light cyan-coloured cells). The MODIS C005 AOD data provide drastic improvement in terms of comparison against AERONET since at only two stations correlation coefficients are smaller than 0.6 (against 4 stations for MODIS C004) and at 5 stations smaller than 0.7 (against 14 stations for C004). In addition, at 14 stations AOD_{550} from C005 is underestimated and at 12 stations it is overestimated.

The improvement of MODIS AOD data from C004 to C005 is clearly shown in Fig. 3b and c, where both sets are compared with AOD data from the 29 AERONET stations, altogether yielding a total of more than 12 000 matched data pairs. The statistics are drastically improved, with the correlation coefficient between MODIS and AERONET increasing from 0.66 for C004 to 0.76 for C005, i.e. by 17%. The scatter of the points is also reduced substantially, with a decreased standard deviation of differences from

0.15 to 0.12, i.e. by 20%. The applied linear regression to the MODIS C005 versus AERONET data is much closer to the 1 to 1 line than the regression of MODIS C004, presenting an offset equal to only 0.04 instead of 0.12 and a slope equal to 0.85 instead of 0.79. Note that Levy et al. (2007b) based on a test bed of 6300 worldwide MODIS granules reported a slope equal to 1.01 and an offset of 0.03. For both collections, MODIS overestimates the lower AOD AERONET values, while underestimating the high AODs, as also reported by other investigators (e.g. Chu et al., 2002; Remer et al., 2005). Nevertheless, there has been an improvement from C004 to C005 data, since in the former case the overestimation extends up to AOD values of about 0.6 while this occurs up to only 0.2 in the latter case. The computed mean AODs and associated standard deviations for the two MODIS Collections and AERONET are given in Fig. 3b and c. There is a significant improvement with the mean C005 AOD_{550} (0.23±0.19) matching amazingly well that of AERONET (0.23±0.17) opposite to the significantly overestimated mean C004 AOD_{550} (0.29±0.20).

Figure 4a presents the overall AOD comparison between the two MODIS collections. There is a very large number of matched data pairs (more than one million), resulting from the 2191 daily values for each one of the 900 geographical cells of the study region, enabling thus good statistics. The correlation coefficient between C004 and C005 equals 0.92 and the standard deviation of the differences between the two collections is 0.07, corresponding to 26% and 32% of the mean C004 and C005 AOD values, respectively. The mean MODIS AOD value has decreased from 0.27±0.21 (C004) to 0.22±0.18 (C005), i.e. by 18.5%. The equation of the linear regression line between the C004 and C005 AOD data over the Mediterranean basin is

$$AOD_{C5}=0.86(AOD_{C4})+0.003 \tag{1}$$

This equation indicates that the MODIS C004 data has been corrected by a factor of 0.86. The small offset of 0.003 reveals that in most cases, the MODIS C005 values are smaller than those of C004. The derived equation is useful for easily adjusting/correcting existing/published AOD values based on the previous Collection 004, over the greater Mediterranean basin.

The comparison between C004 and C005 AOD data is separately shown over land and ocean surfaces in Fig. 4b and c, respectively. It is clear that the correction is much more important over land than over ocean. The correlation coefficient over land equals only 0.88 against a high coefficient of 0.99 over ocean. Moreover, the scatter of points is much larger over land (standard deviation, SD, of differences equals 0.08) than ocean (SD=0.03). Note that the mean MODIS AOD_{550} derived with the new algorithm has increased over ocean from 0.21 to 0.22 (i.e. by 4.8%), while it has decreased significantly (i.e. from 0.31 to 0.23 or by 25.8%) over land. Our results are in line with Levy et al. (2007b) who reported a decrease in AOD_{550} from 0.28 to 0.21 (i.e. by 25%) for a set of about 6300 globally distributed granules of both MODIS Terra and Aqua. The larger correction of AOD over land than ocean is also indicated by the slope of the applied linear regression lines to MODIS C004 versus C005 AOD data, which is much smaller over land (equal to only 0.8) than ocean (as high as 0.99).

The correction of C004 AOD_{550} based on Eq. (1) is valid for the entire range of AODs when the whole study region is considered. More accurate corrections, valid for specific bins of AOD ranging from 0 to 3, are provided in Table 2, where the slope (a) and offset (b) of the applied linear regression lines to the AOD_{C5} vs. AOD_{C4} AOD data are given separately over land, over ocean, and for all areas (land and ocean) together with the computed correlation coefficients between AOD_{C5} and AOD_{C4} AOD values. Note the better agreement between the two MODIS collections over ocean than over land, as indicated by larger slopes and correlation coefficients and smaller offsets. Correction formulas for MODIS C004 AOD values such as those shown in Table 2 are necessary given the identified problems encountered when comparing MODIS against ground-based AERONET data (Fig. 3b).

Apart from changes in regional mean AOD values from Collection 004 to Collection 005, changes in the distribution (histogram) of AODs are also of interest. Figure 5 displays the histograms of retrieved AOD_{550} from both C004 and C005 either for land (Fig. 5a) and ocean (Fig. 5b) areas separately or for the entire study region (Fig. 5c). In all cases, the distribution is unimodal and peaked near 0.12. There is a clear difference between land (Fig. 5a) and ocean (Fig. 5b) concerning AOD changes from C004 to C005. First, the differences between the two collections are small over ocean while they are much larger over land. Secondly, while the AOD is slightly increased from C004 to C005 over ocean for AOD>0.15, it is mainly decreased over land for AOD>0.20. For smaller AODs the opposite is valid over both land and ocean. A similar behaviour has been reported by Levy et al. (2007b) for a set of 6300 MODIS Terra and Aqua granules over land. Nevertheless, there are some differences between the two studies. Levy et al. (2007b) found that AOD is reduced over land for 0.2<AOD<0.75 while it remains about the same for AOD>0.75. In the present study, the AOD_{550} over land is found to be systematically reduced from C004 to C005 for 0.2<AOD_{550} <1.0 up to about 1.0. This is also projected in the results concerning the entire study region (Fig. 5c).

4 Conclusions

The performance of the second generation MODIS algorithm (V5.2) for deriving aerosol optical properties with respect to the previous version (V4.2) was evaluated in this study through inter-comparison against quality ground-based AERONET data. The evaluation was performed for the climatically sensitive greater Mediterranean basin, which is affected by aerosols and their radiative forcing. Six-year (March 2000–February 2006) daily aerosol optical depth data at 550 nm from MODIS-Terra were used in the study together with corresponding data from 29 AERONET stations distributed in the study region. The comparison between the new (C005) and the previous (C004) MODIS algorithm reveals an overall decrease (by 18.5%) in AOD_{550} values over the study region, with the regional mean AOD decreasing from 0.27±0.21 to 0.22±0.18. More specifically, there is a significant decrease in AOD values over land (by 25.8%) against a slight increase over ocean areas (by 4.8%). Specifically, this is found for AOD>0.2 over land and AOD>0.15 over ocean areas in the Mediterranean basin. In contrast, for clean aerosol conditions there is an increase in AOD over land (for AOD<0.2) and a decrease over sea surfaces (for AOD<0.15). This resulted in a much better agreement of C005 than C004 AODs with AERONET data. Thus, the mean AOD values are equal to 0.23±0.19 for C005 and 0.23±0.17 for AERONET, against 0.29±0.20 for C004. The statistics obtained from a large test set (more than 12000 matched data pairs) were greatly improved for C005 compared to C004 with regards to their regression with AERONET data. Thus, the correlation coefficient increased from 0.66 to 0.76, and the slope of the linear regression fit from 0.79 to 0.85 whereas the offset decreased from 0.12 to 0.04 and the scatter of compared data pairs from 0.15 to 0.12. The differences between the MODIS C005 and AERONET AODs lie within the range of uncertainties of the two datasets. Moreover, it is important that no changes in the inter-annual variation between C004 and C005 AODs were found but rather a systematic correction in AODs, i.e. almost constant with time. In addition, despite the decrease in AOD values, the seasonal variation of AOD remains essentially unaffected, though the correction is larger in the drier (March to October) than in the wetter period of the year, i.e. when the region is influenced by dust aerosols transported basically from the North African deserts. The results indicate that the improvement of MODIS C005 AOD data is probably due to the improved estimation of the surface visible reflectance that is calculated in the new algorithm using a parameterized reflection relationship and updated aerosol models. Quick first-order correction equations for size-resolved MODIS AODs based on the previous Collection 004, within the study region, have been derived from the analysis. The C005 AOD data can be more reliably used in various applications and studies for the Mediterranean basin, including those for investigating tendencies in aerosol loads.

Acknowledgements. Christos Papadimas acknowledges support by the PENED 03ED373 grant co-financed by the EU European Social Fund (75%) and the Greek Ministry of Development-GSRT (25%). The authors also acknowledge support by the European Union IP-036961, CIRCE and thank NASA-US for making available the Collection 004 and Collection 005 Level-3 MODIS data and the AERosol RObotic NETwork (AERONET) for providing the AOD data.

References

Barnaba, F. and Gobbi, G. P.: Aerosol seasonal variability over the Mediterranean region and relative impact of maritime, continental and Saharan dust particles over the basin from MODIS data in the year 2001, Atmos. Chem. Phys., 4, 2367–2391, 2004, http://www.atmos-chem-phys.net/4/2367/2004/.

Charlson, R. J., Schwartz, S. E., Hales, J. M., Cess, R. D., Coakley Jr., J. A., Hansen, J. E. and Hofmann, D. J.: Climate forcing by anthropogenic aerosols, Science, 255, 423–430, 1992.

Chin, M., Chu, A., Levy, R., Remer, L., et al.: Aerosol distribution in the Northern Hemisphere during ACE-Asia: results from global model, satellite observations, and sun photometer measurements, J. Geophys. Res., 109(D23), 1–15, 2004.

Chu, D. A., Kaufman, Y. J., Ichoku, C., Remer, L. A., Tanre, D., and Holben, B. N.: Validation of MODIS aerosol optical depth retrieval over land, Geophys. Res. Lett., 29, 8007, doi:10.1029/2001GL013205, 2002.

Dubovik, O. and King, M. D.: A flexible inversion algorithm for retrieval of aerosol optical properties from sun and sky radiance measurements, J. Geophys. Res., 105, 20 673–20 696, 2000.

Dubovik, O., Smirnov, A., Holben, B. N., King, M. D., Kaufman, Y. J., Eck, T. F., and Slutker, I.: Accurancy assessments of aerosol optical properties retrieved from Aerosol Robotic Network (AERONET) Sun and sky radiance measurements, J. Geophys. Res., 105, 9791–9806, 2000.

Dubovik, O., Holben, B. N., Eck, T. F., Smirnov, A., Kaufman, Y. J., King, M. D., Tanré, D., and Slutsker, I.: Variability of absorption and optical properties of key aerosol types observed in worldwide locations, J. Atmos. Sci., 59, 590–608, 2002.

Holben, B. N., Eck, T. F., Slutsker, J., et al.: AERONET – A federated instrument network and data archive for aerosol characterization, Remote Sens. Environ., 66, 1–16, 1998.

Holben, B. N., Tanré, D., Smirnov, A., Eck, T. F., Slutsker, I., Abuhassan, N., Newcomb, W. W., Schafer, J., Chatenet, B., Lavenue, F., Kaufman, Y. J., Vande Castle, J., Setzer, A., Markham, B., Clark, D., Frouin, R., Halthore, R., Karnieli, A., O'Neill, N. T., Pietras, C., Pinker, R. T., Voss, K., and G. Zibordi: An emerging ground-based aerosol climatology: Aerosol Optical Depth from AERONET, J. Geophys. Res., 106, 12 067–12 097, 2001.

Ichoku, C., Chu, D. A., Mattoo, S., Kaufman, Y. J., Remer, L. A., Tanré, D., Slutsker, I., and Holben, B. N.: A spatio-temporal approach for global validation and analysis of MODIS aerosol

products, Geophys. Res. Lett., 29(12), 8006, doi:10.1029/2001GL013206, 2002.
Ichoku, C., Remer, L. A., and Eck, T. F.: Quantitative evaluation and intercomparison of morning and afternoon Moderate Resolution Imaging Spectroradiometer (MODIS) aerosol measurements from Terra and Aqua, J. Geophys. Res., 110(D10), 1–23, 2005.
Intergovernmental Panel on Climate Change (IPCC): Climate Change 2007: the physical science basis: summary for Policymakers, 2007.
Jethva, H., Satheesh, S. K., and Srinivasan, J.: Evaluation of MODIS C004 aerosol retrievals at Kanpur, Indo-Gangetic basin, J. Geophys. Res., 112, D14216, doi:10.1029/2006JD007929, 2007.
Kaskaoutis, D. G., Kosmopoulos, P., Kambezidis, H. D., and Nastos, P. T.: Aerosol climatology and discrimination of different types over Athens, Greece, based on MODIS data, Atmos. Environ., 41, 7315–7329, 2007.
Kaufman, Y. J., Tanré, D., Remer, L. A., Vermote, E. F., Chu, A, and Holben, B. N.:, Operational remote sensing of tropospheric aerosol over land from EOS Moderate-resolution Imaging Spectroradiometer, J. Geophys. Res., 102, 17 051–17 065, 1997.
Kaufman, Y. J., Karnieli, A., and Tanré, D.: Detection of dust over deserts using satellite data in the solar wavelengths, IEEE T. Geosci. Remote, 38, 525–531, 2000.
Kaufman, Y. J., Tanré, D., and Boucher, O.: A satellite view of aerosols in the climate system, Nature, 419, 6903, doi:10.1038/nature01091, 2002.
Kazadzis, S., Bais, A., Amiridis, V., Balis, D., Meleti, C., Kouremeti, N., Zerefos, C. S., Rapsomanikis, S., Petrakakis, M., Kelesis, A., Tzoumaka, P., and Kelektsoglou, K.: Nine years of UV aerosol optical depth measurements at Thessaloniki, Greece, Atmos. Chem. Phys., 7, 2091–2101, 2007, http://www.atmos-chem-phys.net/7/2091/2007/.
Kishcha, P., Starobinets, B., and Alpert, P.: Latitudinal variations of cloud and aerosol optical thickness trends based on MODIS satellite data, Geophys. Res. Lett., 34(5), L05810, doi:10.1029/2006GL028796, 2007.
Koukouli, M. E., Balis, D. S., Amiridis, V., Kazadzis, S., Bais, A., Nickovic, S., and Torres, O.: Aerosol variability over Thessaloniki using ground based remote sensing observations and the TOMS aerosol index, Atmos. Environ., 40, 5367–5378, 2006.
Lelieveld, J., Berresheim, H., Borrmann, S., Crutzen, P. J., Dentener, F. J., Fischer, H., Feichter, J., Flatau, P. J., Heland, J., Holzinger, R., Korrmann, R., Lawrence, M. G., Levin, Z., Markowicz, K. M., Mihalopoulos, N., Minikin, A., Ramanathan, V., de Reus, M., Roelofs, G.

J., Scheeren, H. A., Sciare, J., Schlager, H., Schultz, M., Siegmund, P., Steil, B., Stephanou, E. G., Stier, P., Traub, M., Warneke, C., Williams, J., and Ziereis, H.: Global air pollution crossroads over the Mediterranean, Science, 298, 794–799, 2002.

Levin, Z., A. Teller, E. Ganor, and Yin, Y.: On the interactions of mineral dust, sea-salt particles, and clouds: A measurement and modeling study from the Mediterranean Israeli Dust Experiment campaign, J. Geophys. Res., 110, D20202, doi:10.1029/2005JD005810, 2005.

Levy, R. C., Remer, L. A., Tanré, D., Kaufman, Y. J., Ichoku, C., Holben, B. N., Livingston, J. M., Russell, P. B., and Maring, H.: Evaluation of the Moderate-Resolution Imaging Spectroradiometer (MODIS) retrievals of dust aerosol over the ocean during PRIDE, J. Geophys. Res., 108(D19), 8594, doi:10.1029/2002JD002460, 2003.

Levy, R. C., Remer, L. A., Martins, J. V., Kaufman, Y. J., Plana-Fattori, A., Redemann, J., and Wenny, B.: Evaluation of the MODIS aerosol retrievals over ocean and land during CLAMS, J. Atmos. Sci., 62(4), 974–992, 2005.

Levy, R. C., Remer, L. A., and Dubovik, O.: Global aerosol optical properties and application to Moderate Resolution Imaging Spectroradiometer aerosol retrieval over land, J. Geophys. Res., 112(D13), D13210, doi:10.1029/2006JD007815, 2007a.

Levy, R. C., Remer, L. A., Mattoo, S., Vermote, E. F., and Kaufman, Y. J.: Second-generation operational algorithm: retrieval of aerosol properties over land from inversion of moderate resolution imaging spectroradiometer spectral reflectance, J. Geophys. Res., 112(D13), D13211, doi:10.1029/2006JD007811, 2007b.

Massie, S. T., Torres, O., and Smith, S. J.: Total Ozone Mapping Spectrometer (TOMS) observations of increases in Asian aerosol in winter from 1979 to 2000, J. Geophys. Res., 109(D18), 1–14, 2004.

Meloni, D., di Sarra, A., Pace, G., and Monteleone, F.: Aerosol optical properties at Lampedusa (Central Mediterranean). 2. Determination of single scattering albedo at two wavelengths for different aerosol types, Atmos. Chem. Phys., 6, 715–727, 2006, http://www.atmos-chem-phys.net/6/715/2006/.

Mishchenko, M. I., Geogdzhayev, I. V., Rossow, W. B., Cairns, B., Carlson, B. E., Lacis, A. A., Liu, L., and Travis, L. D.: Long-term satellite records reveal likely recent aerosol trend, Science, 315, 1543, doi:10.1126/science.1136709, 2007.

Moulin, C., Lambert, C., Dayan, U., Masson, V., Ramonet, M., Bousquet, P., Legrand, M., Balkanski, Y., Guelle, W., Marticorena, B., Bergametti, G., and Dulac, F.: Satellite climatology of African dust transport in the Mediterranean atmosphere, J. Geophys. Res., 103, 13 137–

13 144, 1998.

Papadimas, C., Hatzianastassiou, N., Mihalopoulos, N., Querol, X., and Vardavas, I. M.: Spatial and temporal variability in aerosol properties over the Mediterranean basin based on 6-year (2000–2006) MODIS data, J. Geophys. Res., 113(D11), D11205, doi:10.1029/2007JD009189, 2008

Penner, J. E., Dickinson, R. E., and O'Neill, C. A.: Effects of aerosol from biomass burning on the global radiation budget, Science, 256, 1432–1434, 1992.

Remer, L. A., Wald, A. E., and Kaufman, Y. J.: Angular and seasonal variation of spectral surface reflectance ratios: Implications for the remote sensing of aerosol over land, IEEE T. Geosci. Remote, 39(2), 275–283, 2001.

Remer, L. A., Tanré, D., Kaufman, Y. J., Ichoku, C., Mattoo, S., Levy, R., Chu, D. A., Holben, B., Dubovik, O., Smirnov, A., Martins, J. V., Li, R.-R., and Ahman, Z.: Validation of MODIS aerosol retrieval over ocean, Geophys. Res. Lett., 29(12), 8008, doi:10.1029/2001/GL013204, 2002.

Remer, L. A., Kaufman, Y. J., Tanré, D., Mattoo, S., Chu, D. A., Martins, J. V., Li, R. R., Ichoku, C., Levy, R. C., Kleidman, R. G., Eck, T. F., Vermote, E., and Holben, B. N.: The MODIS aerosol algorithm, products and validation, J. Atmos. Sci., 62(4), 947–973, 2005.

Remer, L., Kaufman, Y., Tanré, D.,Mattoo, S., Li, R. R, Martins, J. V., Levy, R., Chu, D. A., Kleidman, R., Ichoku, C., and Koren, I.: Collection 005 Change Summary for MODIS Aerosol (04_L2) Algorithms, available at: (http://modis-atmos.gsfc.nasa.gov/products_C005update.html), 2006.

Santese, M., De Tomasi, F., and Perrone, M. R.: Moderate Resolution Imaging Spectroradiometer (MODIS) and Aerosol Robotic Network (AERONET) retrievals during dust outbreaks over the Mediterranean, J. Geophys. Res., 112(D18), D18201, doi:10.1029/2007JD008482, 2007a.

Santese, M., De Tomasi, F., and Perrone, M. R.: AERONET versus MODIS aerosol parameters at different spatial resolutions over southeast Italy, J. Geophys. Res., 112(D10), D10214, doi:10.1029/2006JD007742, 2007b.

Streets, D. G., Wu, Y., and Chin, M.: Two-decadal aerosol trends as a likely explanation of the global dimming/brightening transition, Geophys. Res. Lett., 33, L15806, doi:10.1029/2006GL026471, 2006.

Tanré, D., Kaufman, Y. J., Herman, M., and Mattoo, S.: Remote sensing of aerosol properties over oceans using the MODIS/EOS spectral radiances, J. Geophys. Res., 102, 16 971–

16 988, 1997.

Tripathi, S. N., S. Dey, Chandel, A., Srivastava, S., Singh, R. P., and Holben, B. N.: Comparison of MODIS and AERONET derived aerosol optical depth over the Ganga Basin, India, Ann. Geophys., 23, 1093–1101, 2005, http://www.ann-geophys.net/23/1093/2005/.

Vardavas, I. M. and Taylor, F. W.: Radiation and Climate, International Series of Monographs on Physics, 138, Oxford University Press, Oxford, UK, 2007.

Vermote E. F., El Saleous, N. Z., and Justice, C. O.: Atmospheric correction of MODIS data in the visible to middle infrared: first results, Rem. Sens. Environ., 83, 97–111, 2002.

Xia, X.-A., Chen, H.-B., and Wang, P.-C.: Validation of MODIS aerosols retrievals and evaluation of potential cloud contamination in East Asia, J. of Environ. Sci., 16(5), 832–837, 2004.

ACPD

8, 16891–16916, 2008

Title Page

Abstract | Introduction

Conclusions | References

Tables | Figures

◀| |▶

◀ ▶

Back | Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

Table 1. Comparison between aerosol optical depth at 550 nm (AOD_{550}) from MODIS-Terra Collection 004 (AOD_{C4}) and MODIS-Terra Collection 005 (AOD_{C5}) datasets against corresponding data (AOD_{AER}) from 29 AERONET stations located in the broader Mediterranean basin, over the period March 2000 to February 2006. The correlation coefficients between MODIS and AERONET AOD values and the correlation coefficients between MODIS Collections 004 and 005 are also given. The yellow and red coloured cells indicate stations for which MODIS AOD values are underestimated or equal, respectively, with respect to those from AERONET. The gray and green cells indicate stations for which the correlation coefficients between MODIS and AERONET AOD data are smaller than 0.7 and 0.6, respectively.

	Station	AOD_{C4}	AOD_{C5}	AOD_{AER}	R_{C4-AER}	R_{C5-AER}	R_{C4-C5}
1	Nes Ziona	0.41±0.23	0.29±0.22	0.25±0.16	0.60	0.74	0.89
2	Cairo Univ	0.43±0.19	0.36±0.20	0.36±0.19	0.57	0.60	0.90
3	Forth-Crete	0.30±0.18	0.24±0.15	0.20±0.11	0.68	0.80	0.91
4	Bucarest	0.28±0.18	0.25±0.18	0.33±0.19	0.87	0.92	0.92
5	Moldova	0.23±0.16	0.21±0.18	0.24±0.16	0.76	0.84	0.91
6	ETNA	0.30±0.21	0.25±0.19	0.19±0.16	0.94	0.83	0.80
7	Messina	0.26±0.18	0.22±0.17	0.24±0.13	0.46	0.51	0.95
8	Lecce Univ	0.26±0.19	0.22±0.18	0.22±0.18	0.73	0.77	0.91
9	IMAA Potenza	0.23±0.16	0.19±0.14	0.13±0.08	0.40	0.41	0.92
10	Rome Tor Vergata	0.29±0.19	0.24±0.18	0.20±0.12	0.73	0.80	0.94
11	IMS Oristano	0.29±0.19	0.22±0.18	0.23±0.16	0.75	0.85	0.92
12	Modena	0.30±0.18	0.26±0.18	0.38±0.22	0.50	0.61	0.88
13	Venice	0.40±0.22	0.33±0.24	0.28±0.20	0.66	0.76	0.91
14	ISPRA	0.36±0.25	0.35±0.27	0.31±0.28	0.64	0.72	0.93
15	Ville Franche	0.22±0.16	0.21±0.15	0.27±0.17	0.67	0.64	0.94
16	Toulon	0.21±0.16	0.16±0.15	0.18±0.11	0.71	0.77	0.95
17	Marseille	0.23±0.16	0.17±0.15	0.25±0.15	0.92	0.83	0.87
18	Realtor	0.23±0.16	0.17±0.15	0.24±0.17	0.93	0.95	0.92
19	Vinon	0.23±0.16	0.17±0.15	0.22±0.15	0.83	0.85	0.92
20	Avignon	0.29±0.18	0.21±0.15	0.22±0.14	0.71	0.80	0.91
21	TOULOUSE	0.31±0.19	0.20±0.15	0.18±0.11	0.61	0.91	0.89
22	Toulouse	0.31±0.19	0.20±0.15	0.23±0.15	0.65	0.82	0.89
23	Barcelona	0.25±0.18	0.22±0.17	0.23±0.14	0.74	0.80	0.95
24	Cabo de Boca	0.23±0.17	0.18±0.13	0.16±0.11	0.69	0.79	0.85
25	El Arenosillo	0.27±0.16	0.16±0.14	0.16±0.13	0.60	0.73	0.87
26	Granada	0.34±0.19	0.27±0.16	0.17±0.12	0.69	0.75	0.89
27	Blida	0.29±0.22	0.24±0.23	0.24±0.19	0.84	0.85	0.94
28	Thala	0.32±0.21	0.24±0.18	0.28±0.19	0.83	0.91	0.90
29	Lampedusa	0.25±0.24	0.24±0.22	0.21±0.16	0.87	0.90	0.99

ACPD
8, 16891–16916, 2008

Table 2. Slope (a-values) and offset (b-values) of applied linear regression fit lines to the MODIS-Terra Collection 005 (AOD_{C5}) versus MODIS-Terra Collection 004 (AOD_{C4}) AOD data over the broader Mediterranean basin. The slope and offset values are separately given over land, over ocean and over land and ocean. The computed correlation coefficients (R) between AOD_{C5} and AOD_{C4} AODs are also given in parentheses together with the slope values.

	$AOD_{C5}=a\times AOD_{C4}+b$					
	a (slope) (R)			b (offset)		
AOD bins	Land	Ocean	Land+Ocean	Land	Ocean	Land+Ocean
0.0–0.1	0.596(0.72)	1.052(0.97)	0.827(0.87)	7×10^{-4}	2.4×10^{-4}	7.7×10^{-4}
0.1–0.2	0.326(0.34)	0.882(0.86)	0.580(0.59)	0.084	0.026	0.057
0.2–0.3	0.203(0.21)	0.792(0.79)	0.439(0.46)	0.180	0.056	0.130
0.3–0.4	0.143(0.15)	0.693(0.68)	0.354(0.36)	0.283	0.120	0.216
0.4–0.5	0.106(0.11)	0.600(0.59)	0.301(0.31)	0.387	0.183	0.305
0.5–0.6	0.138(0.14)	0.500(0.49)	0.272(0.27)	0.461	0.277	0.394
0.6–0.8	0.173(0.17)	0.770(0.73)	0.436(0.43)	0.554	0.171	0.385
0.8–1.0	0.072(0.1)	0.658(0.63)	0.413(0.40)	0.816	0.320	0.528
1.0–1.2	0.068(0.1)	0.551(0.53)	0.400(0.39)	1.012	0.507	0.668
1.2–1.4	0.056(0.1)	0.412(0.42)	0.339(0.32)	1.218	0.772	0.866
1.4–1.6	0.081(0.1)	0.349(0.34)	0.275(0.27)	1.364	0.992	1.094
1.6–1.8	0.380(0.42)	0.439(0.42)	0.447(0.41)	1.017	0.964	0.951
1.8–2.0	0.019(0.0)	0.363(0.39)	0.272(0.27)	1.860	1.197	1.374
2.0–2.4	0.058(0.0)	0.427(0.48)	0.370(0.38)	2.314	1.239	1.374
2.4–2.8	0.570(0.3)	0.271(0.28)	0.249(0.25)	1.105	1.868	1.939
2.8–3.0	–	−0.12(−0.2)	−0.07(−1.0)	–	3.212	3.080

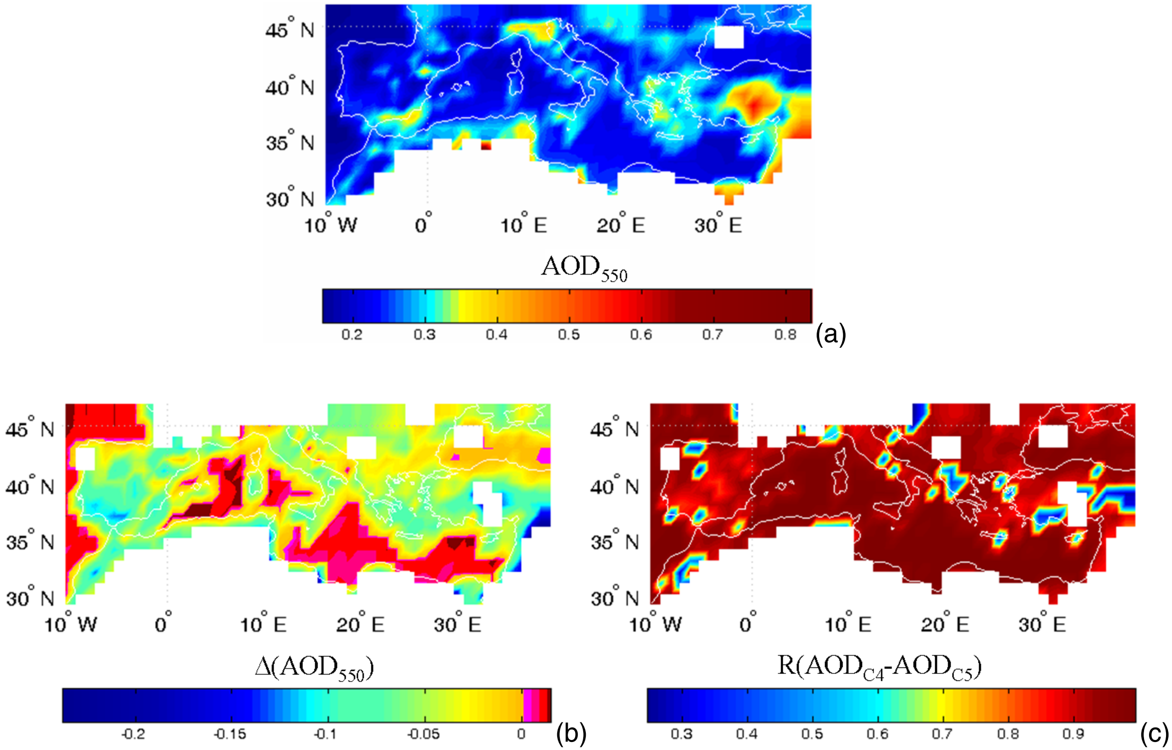

Fig. 1. (a) Six-year (2000–2006) average spatial distribution of aerosol optical depth (AOD) at 550 nm (both land and ocean), over the broader Mediterranean basin based on daily Collection 004 MODIS data. The white areas correspond to 1°×1° longitude-latitude geographical cells with less than 50% of total number of data. **(b)** Spatial distribution of absolute differences between the Collection 005 and Collection 004 MODIS six-year averages of AOD at 550 nm over the broader Mediterranean basin. **(c)** Spatial distribution of correlation coefficients (R) between daily aerosol optical depth data at 550 nm from MODIS Collection 004 (AOD_{C4}) and Collection 005 (AOD_{C5}) over the broader Mediterranean basin (both land and ocean), over the period from March 2000 to February 2006.

ACPD
8, 16891–16916, 2008

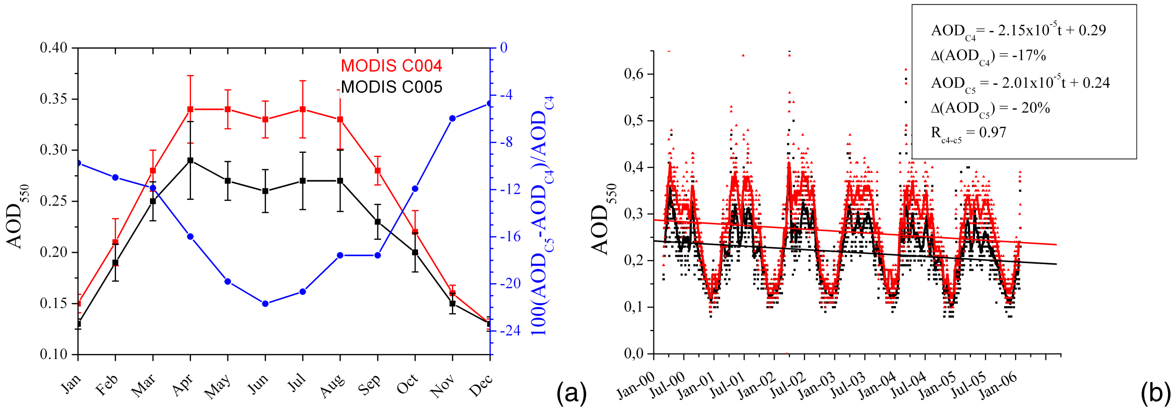

Fig. 2. Seasonal variation of computed six-year (2000–2006) regional (both land and ocean) mean values **(a)**, and time series (2000–2006) of computed daily regional (both land and ocean) mean values **(b)**, of AOD at 550 nm (AOD_{550}) for the broader Mediterranean region based on MODIS-Terra Collection 004 (red line) and Collection 005 (black line) data. In (a) are also given the associated standard deviations and the relative percentage differences (right y-axis), whereas in (b) are also shown the 20-day moving averages smoothed line (bold line) and the linear regression (solid line) applied to the time series.

ACPD

8, 16891–16916, 2008

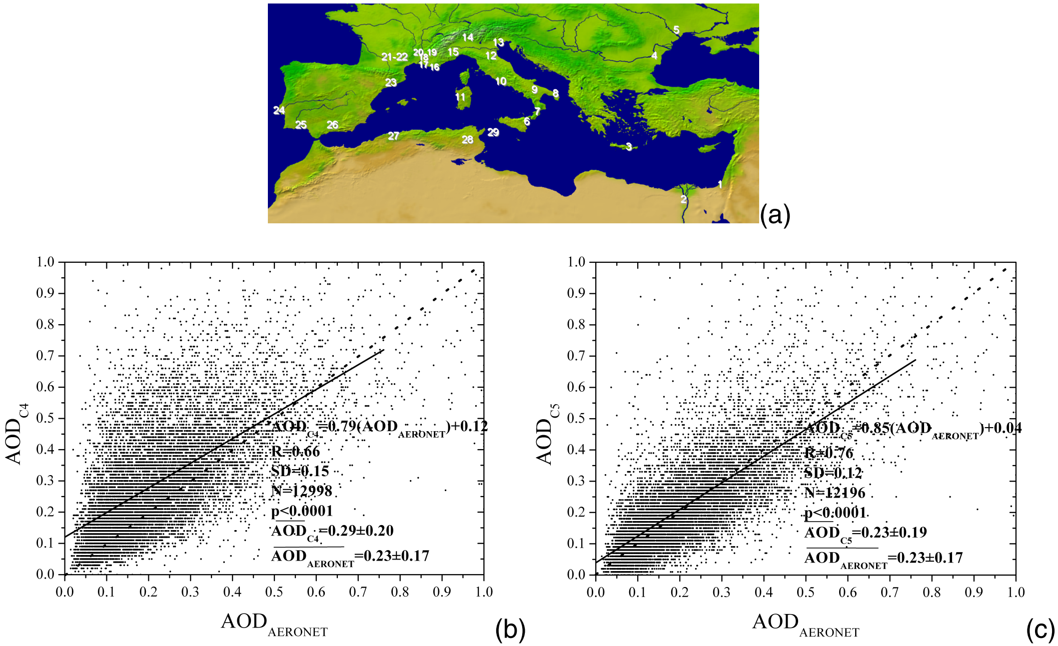

Fig. 3. **(a)** The study region and the location of the 29 selected AERONET stations for inter-comparison of ground-based AOD with MODIS data. **(b)** Scatterplot comparison between daily MODIS-Terra Collection 004 AOD data[a] against those from 29 AERONET stations. **(c)** As in (b) but for MODIS-Terra Collection 005. The correlation coefficient (R) and the standard deviation (SD) of differences between MODIS and AERONET AOD data, the total number of matched data pairs (N), the mean AOD values for MODIS ($\overline{AOD}_{C4}$ and $\overline{AOD}_{C5}$) and AERONET ($\overline{AOD}_{AERONET}$), and the equations for the applied linear regressions between MODIS and AERONET are also given.

[a] Note that very few AOD values larger than 1.0 accounted for in the statistics were omitted from the scatter-plot diagram.

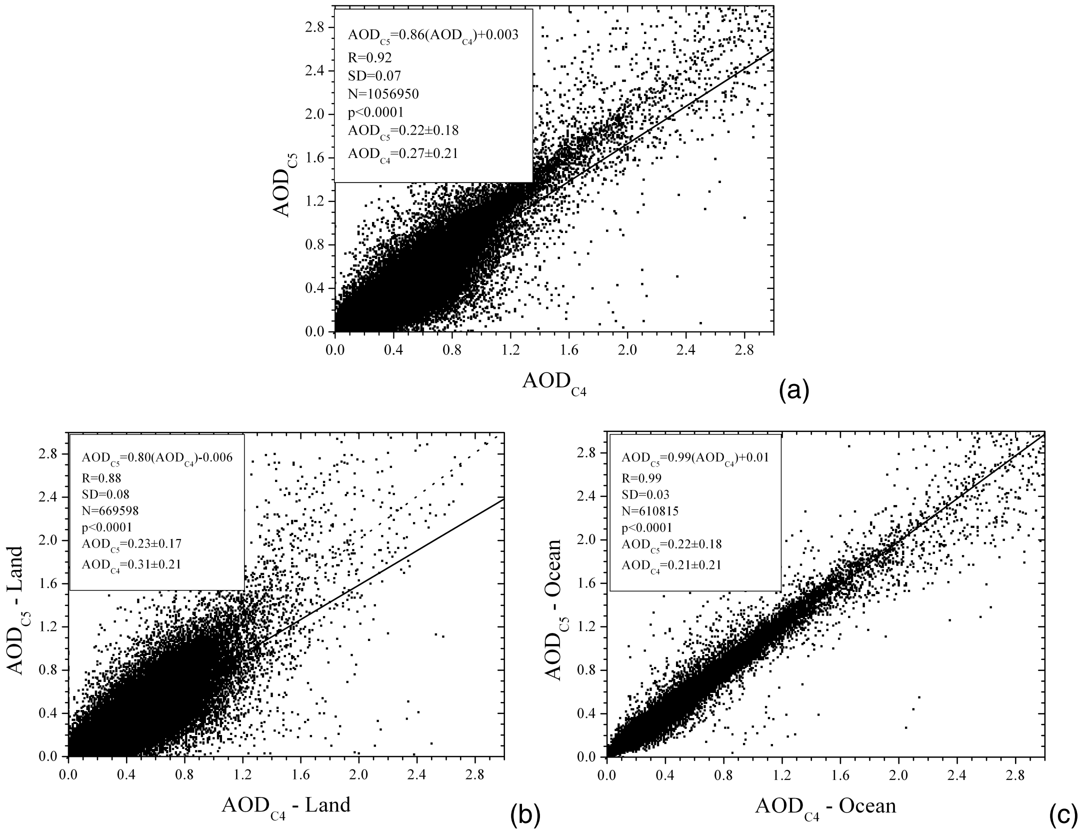

Fig. 4. Scatterplot comparison between daily MODIS-Terra Collection 004 and Collection 005 AOD **(a)**. The comparison is also performed separately over land **(b)**, and ocean **(c)**. The correlation coefficient (*R*) and the standard deviation (*SD*) of differences between C004 and C005 AOD data, the total number of matched data pairs (*N*), the mean AOD values for MODIS C004 (AOD$_{C4}$) and MODIS C005 (AOD$_{C5}$), and the equations for the applied linear regressions between MODIS C004 and C005 are also given.

ACPD
8, 16891–16916, 2008

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

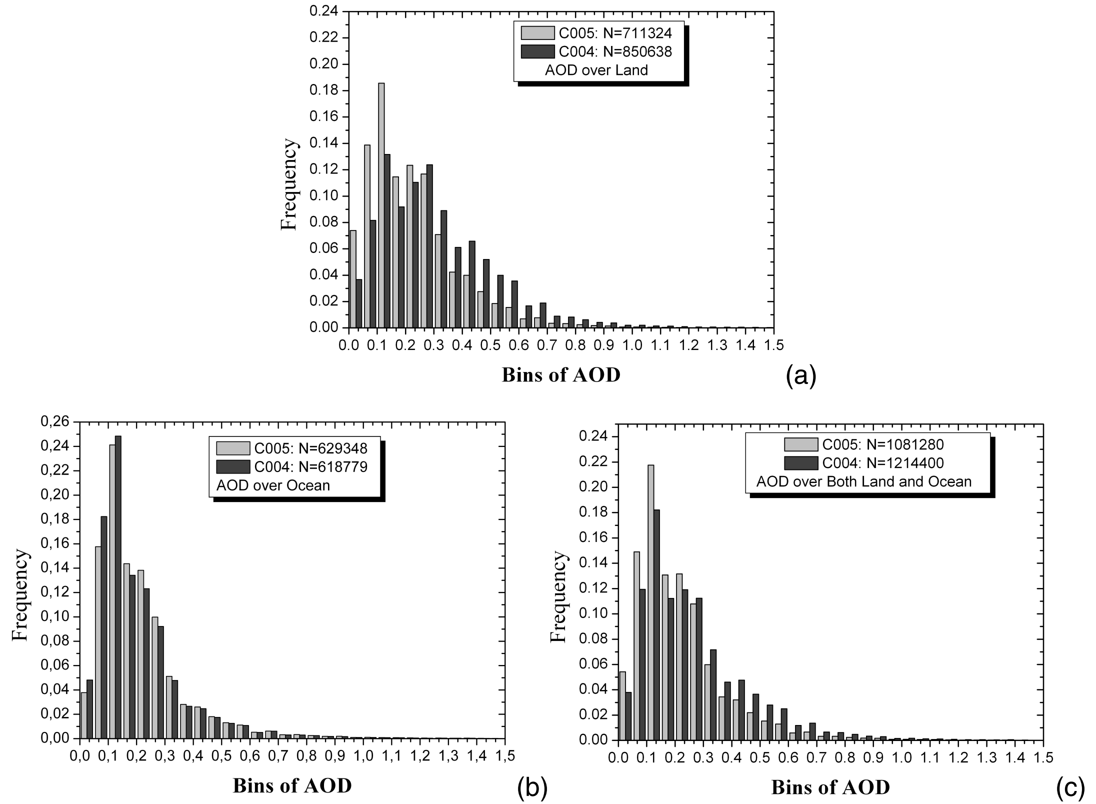

Fig. 5. Histogram[a] of daily MODIS-Terra Collection 005 (in light grey) compared to Collection 004 (deep grey) AOD550 data over land **(a)**, over ocean **(b)** and over land and ocean **(c)** for the broader Mediterranean basin. The value of each bin refers to the minimum value of the bin (the maximum value is the value of the next bin).

[a] Bins corresponding to AOD>1.5 with extremely small frequencies, not seen in the plots, were omitted from the histograms.

ACPD
8, 16891–16916, 2008

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