A 3D aerosol climatology in the atmosphere of Greece by remote sensing & radiative-transfer modeling techniques

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The present study focuses on the climatic analysis of aerosols in Greece using remote sensing methods, in conjunction with the radiative transfer of solar radiation at different altitudes. For this purpose, data from the satellite sensor CALIOP are used as inputs to the solar radiation transfer model (LibRadtran) in order to examine the effects of aerosols on direct solar radiation at different heights in the atmosphere. The distribution of aerosol optical depth and direct irradiance with height revealed that aerosol particles, and in particular dust, have a significant effects on the radiation balance. From the results of this analysis, the attenuation of solar irradiance was also determined based on the difference between measured aerosol and non-aerosol profiles. The dust extinction at western Crete was found to be approximately 0.06 km^{-1} for surface conditions, decreasing to 0.02 km^{-1} at Thessaloniki. The percentage attenuation of the direct irradiance due to the impact of dust is -15% at the surface decreasing to -5% at a height of 1.5 km. This study demonstrates the importance of remote sensing data in helping understand the interaction of aerosols with solar radiation.

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1 Introduction

Aerosols influence the radiative energy budget directly by scattering and absorbing solar radiation, and indirectly by altering cloud droplet size distribution and concentration (Lohmann and Feichter 2005). Estimates of aerosol forcing can be made by coupling radiative transfer model outputs with profile measurements such as those from the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) product that provides extinction and depolarization aerosol profiles at two wavelengths (Winker et al. 2010). The aim of the present study is to present a new method for assessing the aerosol direct effect on radiative transfer based on satellite data.

2 Data and Methodology

2.1 Data

We have used the LIVAS CALIPSO database (developed within the scopes of the ESA project: Lidar Climatology of Vertical Aerosol Structure for Space-Based Lidar Simulation Studies, http://lidar.space.noa.gr:8080/livas/) and the radiative transfer model LibRadTran (Mayer and Kylling 2005), in order to study the radiative effects of aerosols in the Greece region. Aerosol extinction profiles at 532nm have been used in order to calculate the AOD at different heights. The grid used had a spatial resolution of 1 x 1 degree and included measurements from at least 160 CALIPSO overpasses in each cell. Here we present average AODs calculated from CALIPSO measurements collected over the period 2008-2012 (inclusive). Using the aerosol type classification scheme provided by the CALIPSO retrieval algorithm (Winker et al. 2013) we then also extracted the dust-only contribution to the total AOD. In this paper we used unconstrained LIVAS products with respect to the variation of elevation since it has been shown that the contamination of signals near the surface causes high backscatter values and a final overestimation of AOD (Amiridis et al. 2014).

2.2 Methodology

As inputs to the LibRadtran model we used aerosol extinction profiles from CALIPSO and ozone measurements from the Ozone Monitoring Instrument (OMI) onboard the satellite Aura. As outputs we calculated the integrated direct solar irradiance from 300 to 1100 nm which is representative of a wide range of optical masses and atmospheric conditions (Martinez-Lozano et al. 1995). The output heights selected were the ground level, 1.5 km and 3 km and we calculated the mean total and dust-only aerosol profiles per grid cell. The analysis was performed for local noon data with LibRadtran being used to solve the radiative transfer equation and export the calibrated irradiance and integrated solar irradiance.

3 Results

3.1 Vertical variability of atmospheric aerosol profiles

Figure 1 shows the distribution of total AOD at three different heights calculated from the mean CALIPSO aerosol profile in each cell. The AOD is computed from the top of atmosphere down to each altitude level. The aerosol extinction profiles (total and dust-only) at 532nm are presented in Figure 2. Data has been separated at three different latitudes (western Crete, Athens, Thessaloniki) to show the latitudinal variation of average total and dust-only aerosol profiles.

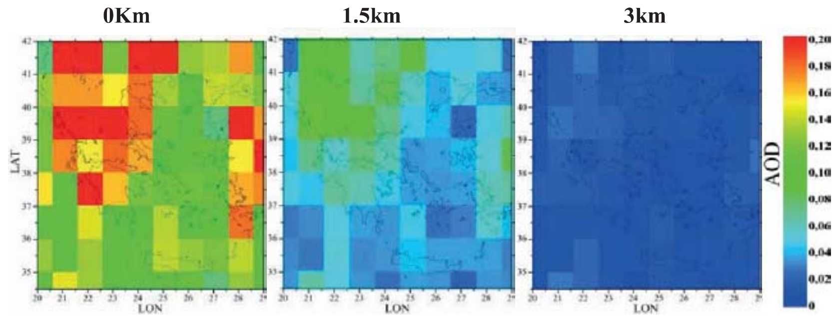

Fig. 1. The AOD distribution over Greece at three heights derived from mean CALIPSO (2008-2012) aerosol profiles.

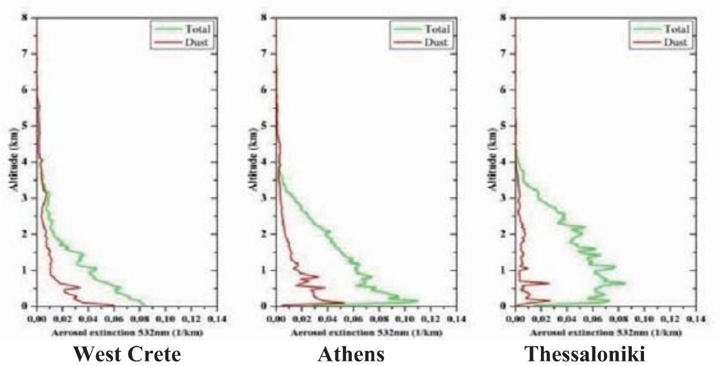

Fig. 2. Mean aerosol extinction profiles at 532nm for total aerosol (green line) and dust-only aerosol (red line) at western Crete, Athens and Thessaloniki.

3.2 Radiative transfer simulation

With this model simulation, an attempt is made to evaluate the influence of aerosols on direct irradiance at various altitudes in the atmosphere. Figure 3 shows the mean noon-time direct solar radiation over Greece. Figure 4 shows the results obtained for the case of dust-only particles when input data to the model is filtered according to the aerosol type classification provided by the CALIPSO algorithm. The decrease of direct irradiance due to aerosol in the layer between 3 km and the ground level ranges from -100 to -150 Wm^{-2} (-80 to -120 for dust). This is compared with the decrease in irradiance due to aerosol in the thinner layer between 3 km and 1.5 km which ranges from -50 to -130 Wm^{-2}. Similar results have been reported by Benas et al. (2011).

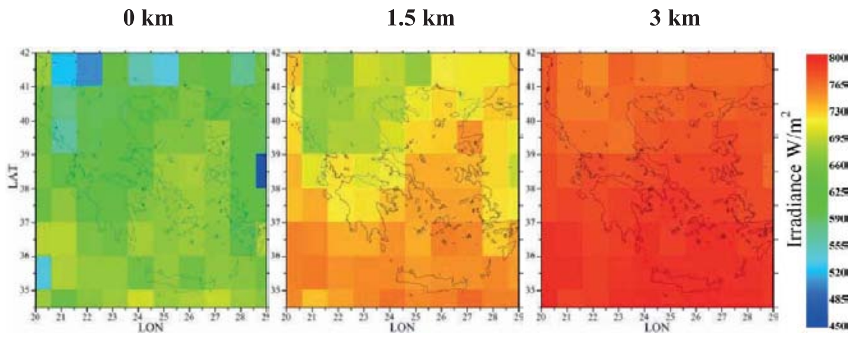

Fig. 3. Computed mean direct irradiance over Greece at 0, 1.5 and 3km for the period 2008-2012.

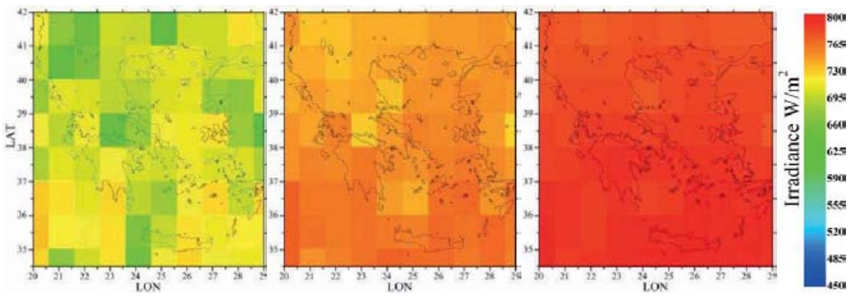

Fig. 4. Computed mean direct irradiance over Greece from dust-only aerosol profile inputs.

3.3 Percentage aerosol attenuation of solar radiation

In this section we present an estimate of the three dimensional attenuation of solar radiation due to the effect of aerosol in the area of Greece. We performed two radiative transfer simulations with LibRadtran. In the first simulation, the atmospheric profile includes the mean CALIPSO total and dust-only aerosol extinction profile in each cell. In the second simulation, the same model settings were used but with clean and clear (aerosol free) atmospheric conditions. The percentage difference between the two situations was then used to estimate the attenuation of direct irradiance due to aerosol at different altitudes. Figure 5 shows the percentage attenuation of direct irradiance and Figure 6 reports the attenuative impact of the dust-only component. The attenuation of the direct irradiance shows a clear altitudinal and geographical dependence over the study region. In particular, the highest attenuation is found over the Greek mainland at the surface level (from -15 to -20%) and, as expected, is slightly lower at 1.5 km (-5 to -12%). The lowest attenuation occurs at 3 km (from -1 to -4%) where aerosol extinction at 532nm is close to zero (see Figure 2). The impact of dust on the attenuation of direct irradiance is maximized at the surface (-14% in southern Greece) falling to -5% at 1.5 km (at the same latitude). In all cases the attenuation is seen to decrease with increasing altitude. While Figure 5 suggests that the percentage attenuation increases also in the north-westerly direction, we recall that the AOD and direct irradiance used as inputs are overestimated due to the contamination of signals near the surface (Amiridis et al. 2014). We also need to point out that although there is a latitudinal dependence of the attenuation on total aerosol, it is not clear that this is due to dust (Figure 6) where almost no latitudinal gradient is observable (especially at the surface) even when we take into account the uncertainty in the CALIPSO retrieval arising from surface contamination effects.

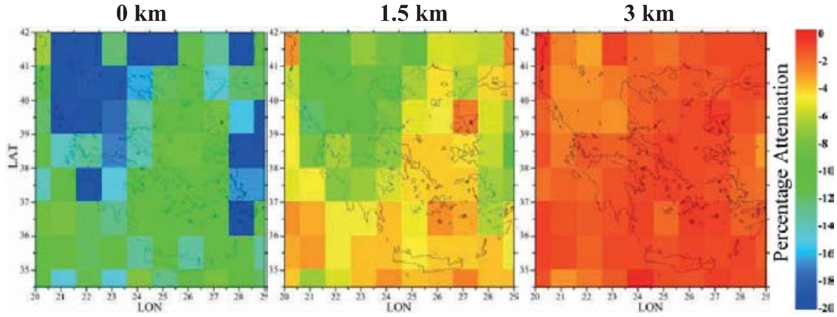

Fig. 5. Percentage attenuation of direct irradiance at three heights

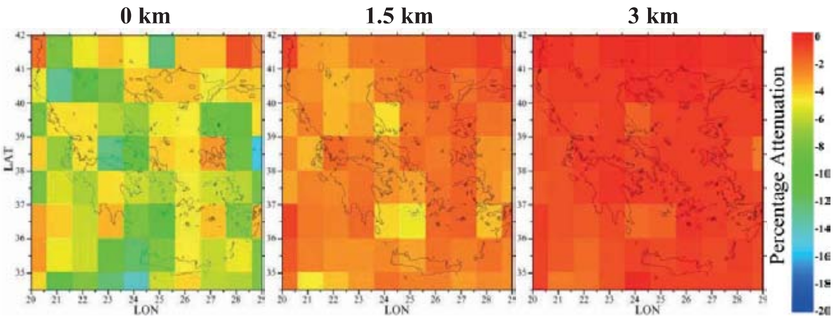

Fig. 6. Dust impact at direct irradiance's percentage attenuation

We also investigated the effect of aerosol on global horizontal irradiance (GHI) and found that the maximum mean attenuation at the surface is around -5% (≈-2% for dust) and at 1.5 km is -1.5% (-1% for dust).

4 Conclusions

In this work the effect of airborne particles on solar radiation was examined with remote sensing measurements and radiative-transfer model simulations. Our findings are consistent and show, in the case of Greece, that as we go higher into the atmosphere, a sharp decrease in aerosol extinction is observed with a corresponding decrease in the attenuation of direct irradiance. A latitudinal variation of solar irradiance associated with total aerosol was seen over Greece but uncertainties arising from surface contamination mean that more work is needed to see whether or not this is associated with frequent African dust transport in the southern parts of Greece. This study highlights the usefulness of vertical profile data as an input to radiative-transfer models whose results can help ascertain the impact of aerosol components on energy balance and therefore the construction of current and future climate and climate change regimes. Knowledge of the vertical distribution of radiation is key to a detailed understanding of the processes taking place in the whole atmospheric column. Various atmospheric photo dissociation rates that have an impact on the atmospheric air quality (NO2, O1D, HCHO) require vertical information of spectral radiation quantities and the use of CALIPSO data in combination with the radiative transfer model presented here, can be used in order to provide such information.

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