Determination of aerosol optical properties using ocean reflectance

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Using multispectral satellite active-sensor observations avoids the uncertainties associated with lidar-inversion algorithms.

Accurate observation of the effects of aerosols (solid particles suspended in the atmosphere) on solar radiation is important, especially because of their significance to climate change. Improvements in aerosol characterization can lead to a better understanding of the scattering and absorption of sunlight. The aerosol optical depth (AOD) is a key parameter in this regard because it quantifies the absorption and scattering of light, and it specifies the atmospheric aerosol burden and aerosol type.

Satellite-based radiometric observations measure the sunlight that is scattered by aerosols. We propose to determine the AOD using the instrumentation onboard the Afternoon satellite constellation (the ‘A-Train’), including measurements of the active ocean-surface echoes obtained by CALIOP (Cloud Aerosol Lidar with Orthogonal Polarization) and CPR (Cloud Profiling Radar). This combined approach improves AOD determination, since no a priori assumptions regarding the aerosol optical properties are required.

CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) and CloudSat offer two co-located, simultaneous measurements of ocean-surface echoes, of which the scattering properties are well understood. Without clouds, lidar and conventional-radar ocean-surface backscatter signals are attenuated mainly by aerosols and water vapor, respectively. After correcting for water-vapor absorption and taking into account wavelength dependencies, the radar signal serves as a reference for the unattenuated lidar measurements. The ratio of the measured lidar surface echo to the reference radar signal provides unambiguous total-column optical thickness at lidar wavelengths.

During the August 2006 wildfire season in central Africa, we applied our newly developed CALIPSO-CloudSat surface-reflectance method (CCSRM) to biomass-burning aerosol, which was advected over the Gulf of Guinea. Results for 17 August 2006 are shown in Figure 1. Our method can be used to retrieve important properties that improve aerosol-type determination. For instance, using the CCSRMs at 532 and 1064nm, we derived AOD values at both wavelengths (with a mean of 0.7 and 0.2 at 532 and 1064nm, respectively) and the Angström exponent (used to describe the AOD dependence on wavelength): see Figure 2. The mean Angström exponent of 1.85

Figure 1. CALIPSO backscattered coefficient at 1064nm (in decimal logarithmic units of sr\(^{-1}\)m\(^{-1}\)), showing the aerosol layer (yellow feature between 2 and 3km altitude) over the ocean (horizontal red line at surface level). Using the left-hand scale as a (dimensionless) measure of the aerosol optical depth (AOD), the respective AODs as a function of latitude at 532 and 1064nm are also indicated, magnified by a factor of ten (black squares) and 20 (red triangles), respectively.

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Figure 2. Distribution of the Ångström coefficient.

Figure 3. Difference distribution between CCSRM and MODIS AODs at 0.5 (left) and 1.06µm (right). The means of the distributions are indicated by the red lines.

Figure 4. Lidar-ratio distribution at 532 (left) and 1064nm (right), in units of sr.

The AOD-distribution difference obtained on the basis of the CCSRM at 532 and 1064nm compared with MODIS (Moderate Resolution Imaging Spectroradiometer) closest-wavelength products is shown in Figure 3. We observe mean differences of 0.03 and −0.12 in AOD, which must be compared with the expected statistical error bar (±0.07) to obtain a measure of their statistical significance. The correlation for the entire month over the Gulf of Guinea is quite high, around 0.89 (linear correlation coefficient) at 532nm.

Combining the AOD value with the vertical profile implied by the backscattering coefficient enables derivation of the lidar ratio, which is the ratio of the total extinction to the backscattering coefficient. Its distribution at 532 and 1064nm is shown in Figure 4. The mean values of 90 and 40sr at 532 and 1064nm, respectively, are consistent with the properties of biomass-burning particles. The higher-than-expected climatological value (expected: 70sr) for the 532nm observations underscores the importance of using the CCSRM-facilitated direct determination rather than assuming certain aerosol types and lidar ratios.

Our method offers a new means for AOD determination and aerosol classification on a global scale, allowing a better discrimination of complex atmospheric regimes with significant vertical and horizontal mixing. We will explore the differences in IR AOD from MODIS in more detail. This will likely lead to better characterization of any wavelength dependence of aerosol properties. Our method can be used in conjunction with a second newly developed method that uses the depolarization of laser signals in liquid-water clouds, which appears to offer more complete tools to characterize optical properties of semitransparent layers (such as aerosols or ice clouds) over the ocean at high resolution. Better characterization of aerosol and ice-cloud optical properties will enable more accurate estimates of their radiative impact.

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