Atmospheric Environment 113 (2015) 140–150

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

A method to estimate missing AERONET AOD values based on artificial neural networks

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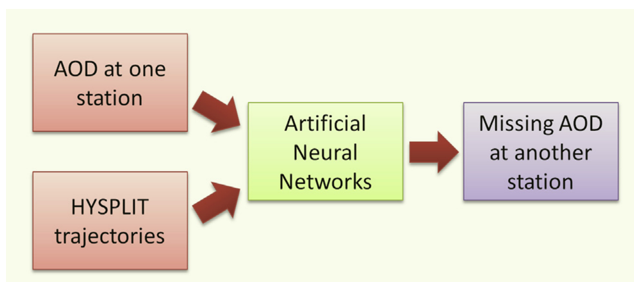
HIGHLIGHTS

- Missing AODs are estimated using AOD at other station, ANN and air mass trajectories.
- The method is particularly useful for cloudy days.
- It was validated in the Eastern US and Iberian Peninsula regions.
- It is suitable for estimating other aerosol optical properties.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 13 November 2014
Received in revised form
5 May 2015
Accepted 8 May 2015
Available online 9 May 2015

Keywords:
AOD prediction
Eastern US region
Iberian Peninsula region
HYSPLIT

ABSTRACT

In this work, we present a method to predict missing aerosol optical depth (AOD) values at an AERONET station. The aim of the method is to fill gaps and/or to extrapolate temporal series in the station datasets, i.e. to obtain AOD values under cloudy sky conditions and in other situations where there is a temporary or permanent lack of data. To accomplish that, we used historical AOD values at two stations, air mass trajectories passing through both of them (calculated by using the HYSPLIT model) and ANN calculations to process all the information. The variables included in the neural network training were the station numbers, parameters representing the annual average trend of meteorological conditions, the number of hours and the distance traveled by the air mass between the stations, and the arrival height of the air mass. The method was firstly applied to predict AOD at 440 nm in 9 stations located in the East Coast of the US, during the years 1999–2012. The coefficient of determination r^2 between measured and calculated AOD values was 0.855, which show the good performance of the method. Besides, this result represents a remarkable improvement compared to three simple approaches. To further validate the method, we applied it to another region (Iberian Peninsula) with different characteristics (lower density of AERONET stations, different meteorology, and lower wind field spatial resolution). Although the results are still good ($r^2 = 0.67$), the performance of the method was affected by these characteristics. Considering the obtained results, this method can be used as a powerful tool to predict AOD values in several conditions. The methodology can also be easily adapted to predict AOD values at other wavelengths or other aerosol optical properties.

1. Introduction

Aerosols are liquid or solid particles suspended in the atmosphere. Hence, they modify the radiation balance of the Earth by

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http://dx.doi.org/10.1016/j.atmosenv.2015.05.009
1352-2310/

scattering and absorbing radiation, leading to two opposite effects: cooling the atmosphere by backscattering the solar radiation to space, and warming it by absorbing the terrestrial radiation (Brooks and Legrand, 2000; Lelieveld et al., 2002). The magnitude of these effects depends, primarily, on the aerosol load (usually quantified through the Aerosol Optical Depth, AOD), chemical composition and size distribution. The balance between these effects is still under discussion, with no unanimous opinion (IPCC, 2007). In addition, the uncertainties in their optical properties and size distribution at local and regional scales are one of the main factors affecting the confidence in the predictive ability of the regional and general circulation models (IPCC, 2007).

The properties of tropospheric aerosols varies widely in time and space due to the different kind of sources, their short residence time (2–7 days), their dependence on relative humidity and their variability in size, shape and chemical composition. Furthermore, aerosols are ubiquitous in the troposphere and can be transported long distances by the wind. Thus, their effects on the atmosphere show a strong temporal and spatial variability. To study the aerosols and to overcome their complexity, both direct measurements and transport models are currently used. One of main sources is the AERONET (AErosol RObotic NETwork) network (Holben et al. 1998, 2001), deployed to retrieve information about local aerosol optical properties in more than 300 sites over the globe in the year 2013 and more than 800 sites since its beginning in 1993. The other relevant source is the satellite measurements, being one of the most complete ones the Moderate-Resolution Imaging Spectroradiometer (MODIS), deployed on board the Terra and Aqua satellites (Salomonson et al., 1992). MODIS has the great advantage of covering the whole globe in a rather homogeneous manner. That is why satellite data are being increasingly used as the main source of AOD data. However, due to uncertainties introduced by surface reflectivity and clouds, aerosol optical properties retrieved from satellites must be validated against surface measurements. Consequently, in this work we used AERONET as the source of data even though its spatial coverage is limited. Regarding the aerosol transport, it can be considered by analyzing the wind fields available from regional and global databases. The most widely used tool to do that is the HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model (Draxler and Hess, 1997, 1998), which is capable of calculating an air mass trajectory forward or backward in time. Both HYSPLIT trajectories and AERONET measurements can be very useful to study different aspects of air masses containing aerosols, but by itself, none of them allows to obtain and correlate information about the evolution of the aerosol properties along a trajectory.

Although AERONET sunphotometers are set up to measure every 15 min, it is very common to have gaps of hours, days or even weeks in the temporal series of optical properties. Beyond the data removal because of the AERONET version 2.0 constraints to assure the data quality, there are several other reasons by which the temporal series can be incomplete, including the instrument going temporarily offline or being relocated, or, mainly, due to the presence of clouds (in many cases during several days). Under these circumstances, the hourly aerosol optical properties values are not available, and the radiative transfer and air quality models that require those parameters as inputs have to be run using average values or crude estimations. Besides, these gaps can lead to a distortion in the statistics of the variables, and bias the long-term analysis and trends. Thus, the aim of this work is to predict a missing AOD value at a site by using the AOD value of a nearby station, provided the trajectory of an air mass passes through both stations. This is accomplished by using neural network calculations that, in turn, use as inputs HYSPLIT trajectories, AOD values at a nearby station and parameterized variables that represent the annual meteorological average trend. In this work, AERONET stations located in the surroundings of Washington, DC, USA (called here Eastern US region) were used as the case study. The zone was chosen because it has high-resolution meteorological databases and presents a high density of AERONET stations. In order to verify the applicability of the method to other regions with different characteristics, we used stations located in Spain, Portugal and Algeria (called the Iberian Peninsula region). This zone is characterized by a lower resolution in the wind fields, and stations sparsely located.

Although the method is used here to predict AOD values measured at 440 nm, it can be also extended to predict values at other wavelengths or different aerosol optical properties. In addition, it can be used not only to fill temporary gaps, but also to extrapolate the AOD values for a period after or before an AERONET station was operative.

2. Databases and tools

In this work, we integrated an aerosol optical properties database (AERONET), with an air mass trajectory model (HYSPLIT) and a predictive tool (Artificial Neural Networks, ANN) to calculate the AOD at a given site. All of them are described in the following sections.

2.1. AERONET

AERONET is a federated international network of radiometers, widely used to retrieve information about local aerosol optical properties (e.g. Putaud et al., 2014; Rahul et al., 2014). The network is coordinated by the NASA Goddard Space Flight Center, which maintains an historical record of over 800 automatic sun/sky CIMEL photometers worldwide. The principle of operation of the CIMEL instrument is to acquire aureole and sky radiance measurements every 15 min, considering that valid measurements are done only when the sun is visible. Sun and sky measurements are performed in seven spectral bands (340, 380, 440/441, 500, 670, 870 and 1020 nm), from which the AOD, Ångström coefficient, size distribution and single scattering albedo, among others, are derived. A detailed description of the instruments and data acquisition procedure was given by Holben et al. (1998, 2001). In this work, only Level 2.0 data were used (cloud screened and quality-assured), even though this largely reduces the number of available values. An accuracy assessment of the AERONET retrievals, as well as the algorithms used to obtain the inversion products, can be found in the work of Dubovik et al. (2000). The results presented in this work are based on the AOD values at 440/441 nm but, for simplicity, they will be referenced as AOD. Tests performed for other wavelength and for Ångström coefficient (not shown here) yields comparable results to those obtained for AOD at 440/441 nm. Thus, the method described here is suitable to be used at any wavelength or for any other aerosol optical properties.

2.1.1. AERONET sites description

The surroundings of Washington, DC are a region with a high number of AERONET stations. We selected an area of about 130 × 300 km (longitude–latitude) that includes nine stations operative in at least 3 months in any year during the period 2004–2012. This area covers the state of Delaware, Washington, DC, and the eastern portions of the states of Virginia and Maryland, totaling about 15 million inhabitants. A map including the locations of the AERONET stations is shown in Fig. 1.

Table 1 contains information about latitudes, longitudes, heights, and period of measurements of all the stations used in this work, together with the number of measurements and the average AOD value.