Atmospheric Environment 128 (2016) 286–304

Contents lists available at ScienceDirect

Atmospheric Environment

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

Characterization of aerosol episodes in the greater Mediterranean Sea area from satellite observations (2000–2007)

A. Gkikas [a, b], N. Hatzianastassiou [a, *], N. Mihalopoulos [c, d], O. Torres [e]

[a] Laboratory of Meteorology, Department of Physics, University of Ioannina, Greece
[b] Earth Sciences Department, Barcelona Supercomputing Center, Spain
[c] Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, Greece
[d] Institute for Environmental Research and Sustainable Development (IERSD), NOA, Athens, Greece
[e] NASA Goddard Space Flight Center, Atmospheric Chemistry and Dynamics Laboratory, Greenbelt, MD 20771, USA

HIGHLIGHTS

- Aerosol episodes of different types are identified for the first time over the entire Mediterranean Sea.
- Satellite based algorithm and data for aerosol optical properties are used together.
- Five types of aerosol episodes are identified with strong spatiotemporal variability.
- Desert dust are the most and biomass-urban the least frequent Mediterranean episodes.
- Mixed aerosol episodes also take place over the Mediterranean Sea.

ARTICLE INFO

Article history:
Received 30 March 2015
Received in revised form
20 November 2015
Accepted 24 November 2015
Available online 2 December 2015

Keywords:
Aerosol episodes
Aerosol type
Dust
Sea-salt
Frequency
Intensity
Satellites
Mediterranean

ABSTRACT

An algorithm able to identify and characterize episodes of different aerosol types above sea surfaces of the greater Mediterranean basin (GMB), including the Black Sea and the Atlantic Ocean off the coasts of Iberia and northwest Africa, is presented in this study. Based on this algorithm, five types of intense (strong and extreme) aerosol episodes in the GMB are identified and characterized using daily aerosol optical properties from satellite measurements, namely MODIS-Terra, Earth Probe (EP)-TOMS and OMI-Aura. These aerosol episodes are: (i) biomass-burning/urban-industrial (BU), (ii) desert dust (DD), (iii) dust/sea-salt (DSS), (iv) mixed (MX) and (v) undetermined (UN). The identification and characterization is made with our algorithm using a variety of aerosol properties, namely aerosol optical depth (AOD), Ångström exponent (α), fine fraction (FF), effective radius (r_{eff}) and Aerosol Index (AI).

During the study period (2000–2007), the most frequent aerosol episodes are DD, observed primarily in the western and central Mediterranean Sea, and off the northern African coasts, 7 times/year for strong episodes and 4 times/year for extreme ones, on average. The DD episodes yield 40% of all types of strong aerosol episodes in the study region, while they account for 71.5% of all extreme episodes. The frequency of occurrence of strong episodes exhibits specific geographical patterns, for example the BU are mostly observed along the coasts of southern Europe and off the Atlantic coasts of Portugal, the MX episodes off the Spanish Mediterranean coast and over the Adriatic and northern Aegean Sea, while the DSS ones over the western and central Mediterranean Sea. On the other hand, the extreme episodes for all but DD aerosol display more patchy spatial patterns. The strong episodes exhibit AOD at 550 nm as high as 1.6 in the southernmost parts of central and eastern Mediterranean Sea, which rise up to 5 for the extreme, mainly DD and DSS, episodes. Although more than 90% of all aerosol episodes last 1 day, there are few cases, mainly extreme DD episodes, which last up to 4 days. Independently of their type, the Mediterranean aerosol episodes occur more frequently in spring (strong and extreme episodes) and summer (strong episodes) and most rarely during winter. A significant year by year variability of Mediterranean aerosol episodes has been identified, more in terms of their frequency than intensity. An analysis of 5-day back trajectories for the most extreme episodes provides confidence on the obtained results of the algorithm, based on the revealed origin and track of air masses causing the episodes. The 25 and 6% of all strong and extreme episodes, respectively, are MX, thus highlighting the co-existence of

* Corresponding author.
E-mail address: nhatzian@cc.uoi.gr (N. Hatzianastassiou).

http://dx.doi.org/10.1016/j.atmosenv.2015.11.056
1352-2310/

different aerosol types in the greater Mediterranean. The intensity of both MX and DSS episodes exhibits similar patterns to those of DD strong ones, indicating that desert dust is a determinant factor for the intensity of aerosol episodes in the Mediterranean, including DSS and MX episodes.

1. Introduction

Aerosol particles along with greenhouse gases are among the most important agents of contemporary Earth's climate change (IPCC, 2013). Aerosols cause an overall planetary cooling partly counterbalancing the global warming induced by greenhouse gases. They interact, through scattering and absorption, primarily with shortwave radiation, but also with longwave one in case of coarse particles. Apart from the Earth's radiation budget, aerosols can also affect the hydrological cycle (Kaufman et al., 2002) by spinning down the tropical water cycle, weakening the Asian monsoons (Lau et al., 2006) or affecting convective storms (van den Heever and Cottom, 2007; Mallet et al., 2009).

Because of the importance of aerosols a great effort is being made in order to better understand their properties and effects. However, despite the significant progress achieved over the last two decades, aerosols are still believed to contribute the largest uncertainty in estimates of current and future climate change (IPCC, 2013). One of the main reasons for this uncertainty is the great variability of aerosols and their sources. Hence, in order to face this problem and improve the scientific knowledge on aerosol properties and effects, there is a need for characterizing aerosols and their sources.

The characterization of aerosol particles can be done using different techniques and types of data, depending on the spatial scale of the analyses. For example, for local studies, aerosol characterization is ideally done through ground in-situ measurements and subsequent chemical analyses and aerosol speciation. On the other hand, for studies with larger spatial coverage, ranging from regional to global, especially those dealing with aerosol climatic and weather effects, the characterization of aerosols needs to be done using atmospheric columnar or range-resolved aerosol data/properties obtained with surface based remote sensing, such as AERONET (Holben et al., 2001; Eck et al., 2005; Kim et al., 2011), MPLNET (Campbell et al., 2008), EARLINET (Papayannis et al., 2005; Mona et al., 2006; Sicard et al., 2011) and other high spectral resolution lidars (e.g. Weinzierl et al., 2011; Groβ et al., 2013, 2015) or with satellite based remote sensing, such as CALIOP-CALIPSO (Mielonen et al., 2009; Burton et al., 2013). The advantage of surface measurements of aerosol properties is their high accuracy, because of which they are considered as the reference, and also the fact that they provide data with high temporal resolution. In contrast, the drawback of surface aerosol properties and data is that they have limited spatial coverage, which is especially desired for regional or global climate studies. On the other side, with the great progress of satellite technology over the last three decades, a global spatial distribution of aerosol properties can be ensured by contemporary satellite sensors, offering a reasonably good accuracy. This advantage has led many scientists to use satellite data in order to study aerosol optical properties globally (Geogdzhayev et al., 2005; Li et al., 2009) or over broad world areas, such as the Mediterranean basin (Barnaba and Gobbi et al., 2004; Hatzianastassiou et al., 2009), Europe (Koelemeijer et al., 2006), Atlantic Ocean (Kaufman et al., 2005), Middle East (Aloysius et al., 2009) and East Asia (Choi et al., 2009). The characterization of aerosols is also important under conditions of unusually high aerosol loadings, so-called *aerosol episodes* or *aerosol events*. This is not only due to the risks and damages that they cause, e.g. on human health, crops or transports, but also because these episodes, which take place more or less sporadically in both spatial and temporal terms, partially account for the great aerosol variability.

In the present study, for the first time to our knowledge, a characterization of aerosols is attempted over sea surfaces of the greater Mediterranean basin, namely the Mediterranean Sea, but also the Black Sea and Atlantic Ocean areas off the coasts of Iberian Peninsula and Morocco, under conditions of intense aerosol episodes. The selection of the specific study region is made because this is a unique area hosting a variety of aerosol types and emission sources (Lelieveld et al., 2002). The Mediterranean is an ideal case for aerosol studies, especially related to climate change, since it is a climatically sensitive region (IPCC, 2013) with islands and coastal areas (e.g. North Africa, Crete island) threatened by desertification. The study region is a semi-enclosed sea surrounded by continental areas of various nature and it is characterized by high aerosol loads (Husar et al., 1997; Ichoku et al., 2002; Papadimas et al., 2008, 2009) and large direct radiative effect (e.g. Hatzianastassiou et al., 2004, 2007; Papadimas et al., 2012). The high aerosol load in the Mediterranean is due to its proximity to the Earth's largest dust source areas, i.e. the Saharan, Middle-East and Arabian deserts, but it is also associated with its location on the pathways of transported aerosols from nearby (Europe) or remote (North America or Asia) anthropogenic sources. It should be noted that land areas are excluded from the present analysis because some input satellite data (especially related to aerosol size, as explained in sect. 2.1) to the algorithm that performs the characterization of aerosol episodes (sect. 2.2) are not considered to meet the required scientific quality standards, making thus questionable the other than desert dust identified aerosol episodes over continental areas. Specifically, however, as it has been shown by Gkikas et al. (2013; 2015b), in case of massive dust episodes, our algorithm along with these satellite aerosol input data performs adequately well.

The present study is an improvement to previous ones, which dealt with different types of aerosol episodes in the Mediterranean basin such as: desert dust (Kubilay et al., 2003; Collaud Coen et al., 2004; Lyamani et al., 2005; Papayannis et al., 2005; Cachorro et al., 2006; Pérez et al., 2006; Toledano et al., 2007; Meloni et al., 2008), fine pollution (Kukkonen et al., 2005; Ladstätter-Weißenmayer et al., 2007; Sciare et al., 2008), forest fires (Balis et al., 2003; Niemi et al., 2005; Pace et al., 2005) or sea-salt aerosols (Marenco et al., 2007). However, most of these studies were focused on single specific aerosol types, while they have been done using surface-based data for a sole or a few locations within the basin. Nevertheless, given the strong spatial variability of aerosol properties, it is important to ensure a broader, complete if possible, spatial coverage. In addition, it is also important to make a comparative assessment of the contribution of the different types of aerosol episodes.

According to the above mentioned requirements, an innovative approach for studying aerosol episodes in the Mediterranean basin has been first introduced by Gkikas et al. (2009), who established an objective and dynamical algorithm, using daily aerosol optical depth values at 550 nm (AOD_{550}) taken from MODIS-Terra satellite.