An assessment of Biomass Burning Aerosol Optical Properties over the Mediterranean Basin based on Satellite Data

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Abstract

The Mediterranean basin is characterized by the coexistence of various aerosol types such us anthropogenic, desert dust, biomass burning (BB) and background marine particles, with relatively high aerosol load affecting the regional radiative budget. This diversity results in complex aerosol properties with high temporal and spatial variability, which is enhanced by the sporadic character of dust transport and wildfire events. The impact of aerosol load on the regional or local radiative budget is intensified during the summer cloud-free period due to the intense solar radiation. During the warm period the Mediterranean experiences the impact of BB emissions when forest and shrubland fires occur due to favorable meteorological conditions. BB aerosols consisting of two major components, black carbon which is the most absorbing aerosol species and organic aerosols that scatters solar radiation, can have a strong impact on the solar radiation budget, altering atmospheric temperature lapse rates and dynamics over a region. In this work an assessment of temporal variability and spatial distribution of biomass burning aerosol optical properties over the broader Mediterranean basin for the period 2002-2016 is conducted. To that end satellite databases are used. At first, wildfire events are identified in terms of ignition date and geographical location based on MODIS (MODerate resolution Imaging Spectroradiometer) collection 006 data. For our analysis wildfires with a burned area of at least 500ha are considered. Then, for each event aerosol optical properties namely spectral AOD, Ångström Exponent (AE), Fine Fraction (FF) and Aerosol Index (AI), that describe the atmospheric load and size of BB aerosols, are assessed. The relevant data are derived from Collection 006 MODIS - Terra database, except for AI which is taken from TOMS (Total Ozone Mapping Spectrometer) and OMI-Aura (Ozone Monitoring Instrument) databases for the periods 2002-2004 and 2005-2016, respectively. The spatial distribution and the inter-annual variability of BB aerosol optical properties are analyzed. The AI values are greater than 2 with maxima attaining 4.3. Ångström Exponent presents a mean value around 1.5 with maxima exceeding 2.5, whereas mean value of FF is about 0.84. AOD (AOD550) can reach values up to 3.3. For selected large wildfire events (mega-fires) the spatial expansion of smoke plume is estimated through forward - trajectories using the HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) model and then BB aerosol properties are calculated over areas affected by the smoke.

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1. INTRODUCTION

The Mediterranean basin is marked by the coexistence of various aerosol types such us anthropogenic, desert dust, biomass burning (BB) and background marine particles, with relatively high aerosol load affecting the regional radiative budget. This diversity results in complex aerosol properties with high temporal and spatial variability, which is enhanced by the sporadic character of dust transport and wildfire events. The impact of aerosol load on the regional or local radiative budget is intensified during the summer cloud-free period due to the intense solar radiation. During the warm period Mediterranean experiences the impact of BB emissions when forest and shrubland fires occur due to favorable meteorological conditions. BB aerosols consisting of two major components, black carbon which is the most absorbing aerosol species and organic aerosols that scatters solar radiation, can have a strong impact on the solar radiation budget, altering atmospheric temperature lapse rates and dynamics over a region.

In this work an assessment of BB aerosol optical properties in terms of Aerosol Optical Depth (AOD), Angstrom Exponent, Fine Fraction (FF) and Aerosol Index (AI), over the broader Mediterranean basin for the period 2002-2016 is conducted.

2. DATA

Study Area: the broader Mediterranean basin, latitude: 33°N - 60°N, longitude: 11°W - 35°E

Time Period: 2002 – 2016

Fire Data: obtained from the MCD64monthly Collection 6 MODIS database at a spatial resolution of 500 m

- wildfire ignition date
- circumference of burned area

Aerosol Optical Properties Data:

- Aerosol Optical Depth (**AOD**) at 470, 550 & 660 nm (AOD_{470}, AOD_{550}, AOD_{660}) over **land**
- Aerosol Optical Depth (**AOD**) at 470, 550, 660, 870, 1240, 1640 & 2130 nm (AOD_{470}, AOD_{550}, AOD_{660} , AOD_{870} , AOD_{1240} , AOD_{1640} , AOD_{2130}) over **ocean**

Level 3 daily 1°x1°values from Collection 006 MODIS-Terra database

- AOD_{550} of fine particles over ocean
- Aerosol Index (**AI**) from TOMS database for the years 2002 – 2004 at 1°×1.25° spatial resolution
- Aerosol Index (**AI**) from OMI database for the years 2005 – 20016 at 1°×1° spatial resolution

The following parameters have been calculated:

Angstrom Exponent ($\alpha_{470\text{-}660nm}$) over **land**

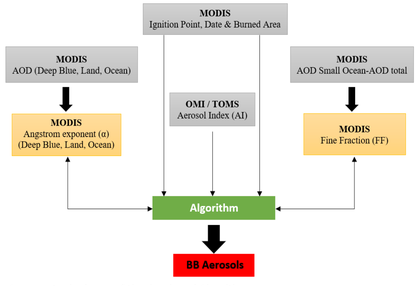
Angstrom Exponent ($\alpha_{550\text{-}870nm}$) over **ocean**

Fine Fraction **(FF)** at 550 nm over **ocean**

3. METHODOLOGY

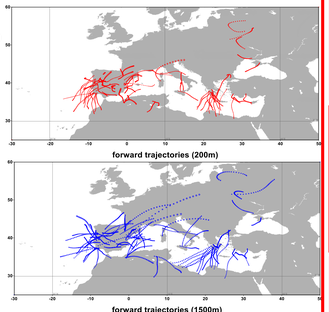
- Total burned area estimation for each wildfire
- Only wildfires with at least 500ha burned area (2533 events taking place in 871 days) are considered
- Based on the burned area coordinates, wildfires are located in pixels of 1°x1° spatial resolution
- Wildfires allocated in the same pixel and/or wildfire events ignited on at least two consecutive days are considered as one event

Algorithm was run for the wildfire event ignition day (D day) and for previous one (D-1)



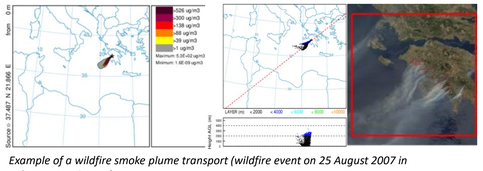
A conceptual scheme of the developed Algorithm

- Depending on prevailing synoptic conditions, wildfire plumes are spatially extended and transported
- To explore the distance to which smoke plume is transported, forward air mass trajectories are calculated for a representative number of wildfire events using HYSPLIT (Hybrid Single Particle Lagrangian Integrated Trajectory Model) model and the GDAS (Global Data Assimilation System) database. Forward trajectories are calculated:
- at 200m and 1500m altitude
- for 24 hours with a 3 hours step

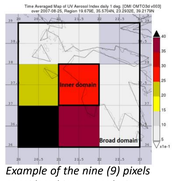


Examples of forward air mass trajectories for wildfire events analyzed

- Forward air mass trajectories analysis has shown that smoke plume is transported in great distances away from the ignition point pixel to the contiguous ones and even further
- In the majority of wildfire events maximum values of the aerosol properties are found in different than the ignition point pixel (e.g. in the following example, AI presents its maximum values in two neighborhood pixels



Example of a wildfire smoke plume transport (wildfire event on 25 August 2007 in Peloponnese-Greece)

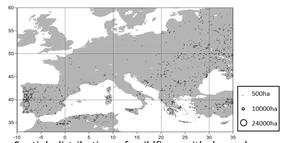


Example of the nine (9) pixels considered in our analysis

•The algorithm for the D day, provides aerosol properties values for the ignition point pixel and for all the 8 vicinity pixels as well

• For our statistical analysis, the two higher values are retained while for event with several days duration, the day with highest values is considered

4. RESULTS



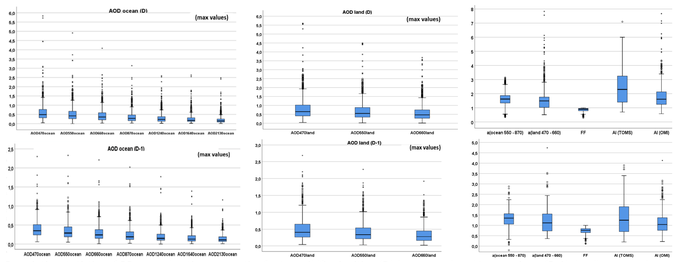
Spatial distribution of wildfires with burned area greater than 500 ha

- Wildfires present high density in the Iberian peninsula, along the coast of northwestern Africa, southern Italy, continental Greece, Anatolia inland and eastern Balkans
- Numerous wildfires in Ukraine are caused mostly by human activities (e.g. agricultural practices)

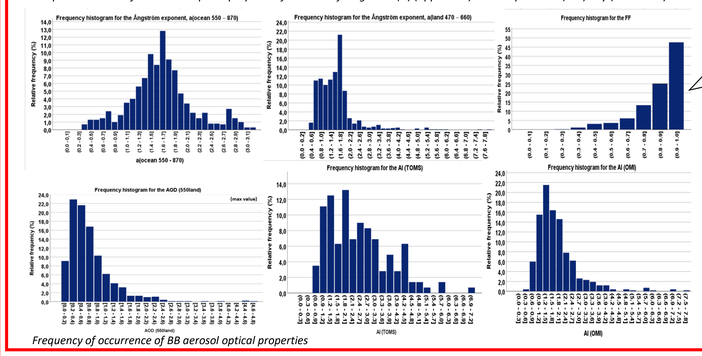
Table 1. *Basic statistics of BB aerosol optical properties*

DAY	MAX VALUES														
	AOD (ocean470)	AOD (ocean550)	AOD (ocean660)	AOD (ocean870)	AOD (ocean1240)	AOD (ocean1640)	AOD (ocean2130)	AOD (land470)	AOD (land550)	AOD (land660)	$a_{550\text{-}870}$ (ocean)	$a_{470\text{-}660}$ (land)	FF	AI TOMS (2002 - 2004)	AI OMI (2005 - 2016)
Mean	0,65	0,56	0,49	0,39	0,33	0,28	0,23	0,81	0,69	0,59	1,63	1,53	0,85	2,50	1,83
Std. Deviation	0,60	0,52	0,45	0,37	0,33	0,30	0,27	0,63	0,54	0,47	0,53	0,78	0,14	1,22	0,94
P10	0,23	0,19	0,14	0,11	0,09	0,07	0,05	0,26	0,20	0,16	1,00	0,75	0,64	1,20	0,98
P25	0,32	0,27	0,21	0,16	0,13	0,12	0,09	0,41	0,34	0,28	1,34	1,03	0,79	1,40	1,24
P75	0,78	0,68	0,60	0,47	0,38	0,32	0,25	1,02	0,88	0,75	1,87	1,76	0,96	3,28	2,13
P90	1,18	1,10	0,98	0,84	0,73	0,62	0,51	1,54	1,34	1,14	2,34	2,14	0,99	4,30	2,84
min	0,05	0,00	0,03	0,03	0,02	0,02	0,01	0,04	0,02	0,01	0,35	0,51	0,30	0,70	0,58
max	5,83	4,96	4,54	3,14	2,59	2,63	2,48	5,60	4,49	3,68	3,14	7,83	1,00	7,10	7,15
Median	0,50	0,42	0,36	0,29	0,23	0,18	0,15	0,65	0,55	0,47	1,62	1,49	0,90	2,30	1,61

DAY - 1	MAX VALUES														
	AOD (ocean470)	AOD (ocean550)	AOD (ocean660)	AOD (ocean870)	AOD (ocean1240)	AOD (ocean1640)	AOD (ocean2130)	AOD (land470)	AOD (land550)	AOD (land660)	$a_{550\text{-}870}$ (ocean)	$a_{470\text{-}660}$ (land)	FF	AI TOMS (2002 - 2004)	AI OMI (2005 - 2016)
Mean	0,41	0,35	0,30	0,26	0,21	0,18	0,15	0,49	0,41	0,33	1,31	1,16	0,73	1,37	1,15
Std. Deviation	0,25	0,24	0,23	0,22	0,19	0,16	0,14	0,32	0,28	0,24	0,45	0,48	0,16	0,85	0,53
P10	0,15	0,12	0,10	0,08	0,06	0,05	0,04	0,17	0,14	0,10	0,66	0,61	0,50	0,40	0,56
P25	0,24	0,19	0,15	0,12	0,10	0,08	0,07	0,26	0,21	0,16	1,06	0,73	0,65	0,70	0,76
P75	0,51	0,45	0,38	0,32	0,26	0,22	0,19	0,65	0,54	0,45	1,56	1,55	0,84	1,90	1,37
P90	0,73	0,65	0,58	0,51	0,44	0,38	0,32	0,87	0,73	0,62	1,87	1,74	0,90	2,60	1,84
min	0,06	0,05	0,01	0,02	0,00	0,01	0,01	0,04	0,03	0,02	-0,20	0,36	0,11	0,20	0,22
max	2,30	2,33	2,21	2,02	1,77	1,39	1,16	2,69	2,27	1,92	2,88	4,74	1,00	3,90	4,13
Median	0,35	0,29	0,24	0,19	0,15	0,13	0,11	0,41	0,34	0,28	1,35	1,12	0,76	1,25	1,04



Descriptive statistics of BB aerosol optical properties for the wildfire ignition (D) (upper row) and the previous (D-1) day (lower row)



Frequency of occurrence of BB aerosol optical properties

During fire days,

- mean values of max AOD at visible wavelengths are greater than 0.5, with values above land being higher than above ocean
- 10% of max AOD values at visible wavelengths are higher than 1.0 and 1.14 over ocean and land respectively
- mean values of Angstrom Exponent are equal to 1.53 and 1.63 over land and ocean respectively while medians are higher than 1.5
- fine particles dominate the aerosol load (mean value of FF is equal to 0.85)
- wildfire events are associated with large AI values. The 75% of AI (OMI) are higher than 1.24 with a mean value of 1.83
- for all BB aerosol optical properties medians, take values lower than averages

Generally, for all AOD mean values of D day are higher than respective means of D-1 day

•Angstrom Exponent during wildfire days presents an increase of 15%-36% above ocean and 25%-42% over land compared to the previous day (D-1)

• For the wildfire days, AI (OMI) increases by up to 75% against the day before

Table 2. *Differences (%) of BB aerosol optical properties between D and D-1 day*

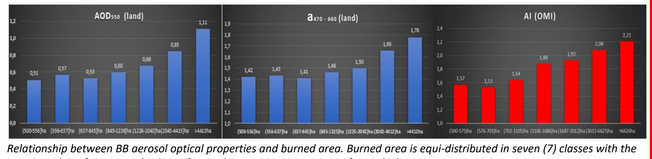
	$a_{550\text{-}870}$ (ocean)			$a_{470\text{-}660}$ (land)			FF			AI (TOMS)			AI (OMI)		
YEAR	D	D-1	%	D	D-1	%	D	D-1	%	D	D-1	%	D	D-1	%
2002	1,61	1,33	21,1	1,62	1,22	32,8	0,82	0,69	18,8	2,10	1,34	56,7			
2003	1,61	1,31	22,9	1,55	1,15	34,8	0,84	0,70	20,0	2,62	1,29	103,1			
2004	1,57	1,20	30,8	1,45	1,16	25,0	0,81	0,69	17,4	2,77	1,50	84,7			
2005	1,61	1,38	16,7	1,73	1,23	40,7	0,86	0,73	17,8				1,82	1,21	50,4
2006	1,58	1,36	16,2	1,46	1,19	22,7	0,80	0,69	15,9				1,62	1,10	47,3
2007	1,71	1,34	27,6	1,55	1,22	27,0	0,87	0,75	16,0				1,97	1,13	74,3
2008	1,69	1,28	32,0	1,51	1,13	33,6	0,85	0,72	18,1				1,80	1,07	68,2
2009	1,55	1,35	14,8	1,51	1,11	36,0	0,85	0,74	14,9				1,75	1,06	65,1
2010	1,57	1,29	21,7	1,45	1,13	28,3	0,86	0,75	14,7				1,96	1,12	75,0
2011	1,69	1,24	36,3	1,52	1,16	31,0	0,89	0,75	18,7				1,73	1,03	68,0
2012	1,57	1,36	15,4	1,51	1,08	39,8	0,82	0,70	17,1				1,82	1,16	56,9
2013	1,57	1,27	23,6	1,46	1,09	33,9	0,88	0,74	18,9				1,80	1,15	56,5
2014	1,63	1,27	28,3	1,51	1,19	26,9	0,90	0,75	20,0				1,99	1,20	65,8
2015	1,67	1,33	25,6	1,71	1,20	42,5	0,87	0,76	14,5				1,86	1,22	52,5
2016	1,66	1,27	30,7	1,47	1,15	27,8	0,85	0,73	16,4				1,77	1,25	41,6

• In the 85% of wildfire days, FF values exceed 0.7 implying dominance of fine particles

• In the 75% of wildfire events AI (OMI) is higher than about 1.4

• 61% of $\alpha_{550\text{-}870}$ (ocean) and 49% of $\alpha_{470\text{-}660}$ (land) values is greater than 1.5

• In the 60% of cases, AOD_{550} (over land) ranges between 0.2 and 0.8, and for the 20% of events exceeds 1.0



Relationship between BB aerosol optical properties and burned area. Burned area is equi-distributed in seven (7) classes with the same number of events and values of optical properties are averages for each class

- A clear positive relation is established between BB aerosol optical properties and burned area
- This correlation is more pronounced for burned area greater than 1000 ha

5. CONCLUSIONS

- An important increase of biomass burning aerosols optical properties values is observed compared to days preceding wildfire events
- A forward trajectories air mass analysis proved that wildfires smoke plumes dispersion and transportation away from the ignition point should be taken into account in the assessment of BB aerosol optical properties
- During wildfire events fine fraction (FF) presents increased values (mean value equal to 0.85 while in the 85% of events exceeds 0.7) implying dominance of fine particles
- A clear positive correlation is shown between BB aerosol optical properties and burned area particularly for areas greater than 1000 ha

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