Radiative effects of biomass burning aerosols in the Mediterranean region during ITOP 2004

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1. Introduction

The Mediterranean region is affected by biomass burning (BB) aerosols either transported from other regions like North America and North-eastern Europe or produced locally due to warm and dry summers characterising the Mediterranean climate, which favour the ignition and the expansion of fires. These aerosols affect the regional climate, as the BB aerosols influence both the chemical composition of the atmosphere by deteriorating the air quality and the radiative equilibrium of the atmosphere, which finally modifies the mesoscale dynamics by changing the heating rate. The relatively minor importance of Mediterranean fires to the earth climate did not permit the occupation of the scientific community with them up to recently, and for this reason the studies of biomass burning aerosols are scarce in this area. Albeit, the Mediterranean region is very vulnerable to climatic change in comparison with other regions of the Earth, which in turns points also to the need of studying the impacts of BB aerosols transported from other regions to the Mediterranean basin.

4. SW radiative impacts of aerosol layers and their transport

The radiative impacts are calculated for two layers of 24 July 2004 with τ at 316 nm of 0.12 for the morning one and 0.26 for the noon one, with τ at 550 nm to be about the half. At the TOA the radiative forcing for the continental average model is always negative, while for the urban model it can be both depending on time (Fig. 4a). The mean daily value for the continental model is -3.3 Wm^{-2}, while for the urban model is 0.7 Wm^{-2}. On the other hand, at the BOA the situation is simpler with cooling for both models and average diurnal values -7.0 Wm^{-2} for the continental model at morning and -23.2 Wm^{-2} for the urban model at afternoon (Fig. 4b). The instantaneous SW heating rate presents higher values for the urban model, which may attain 8 K/day for SZA=0°, while the continental model may reach up to 5.5 K/day. Its minimum average daytime value for null relative humidity is 1.58 K/day (continental-morning) and the maximum is 3.02 K/day (urban-noon), while the respective daily values are 0.9 K/day and 1.8 K/day (Fig. 4c). On the other hand, Figure 4d shows that the heating rate does not change only at the level of the aerosol layer, but also it varies below it around noon.

Except from the estimation of the radiative impacts for these BB aerosols, the use of the Lagrangian particle dispersion model FLEXPART (Stohl et al., 2005) permits the calculation of the forward trajectories in order to find out the evolution of the BB plumes. It can be seen that the layer around noon of 24 July continues its journey in the Mediterranean basin (Fig. 5a) and a part of this is redetected two days later by the NTUA Raman lidar system over Athens (Fig. 5b).

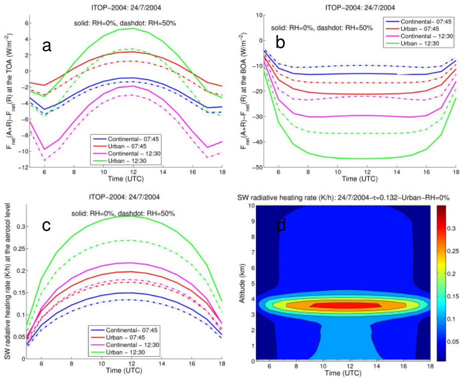

Figure 4: Temporal evolution of a) radiative forcing at the TOA, radiative forcing at the BOA, c) heating rate at the aerosol level and d) altitude dependence of heating rate for the urban model (RH=0%).

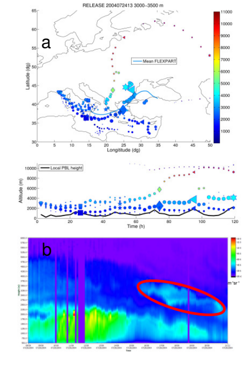

Figure 5: a) Forward FLEXPART trajectories released on 24 July between 3 and 3.5 km asl at 13 UTC and b) aerosol backscatter coefficient at 355 nm measured at 26 July 2004 over Athens.

2. Data set and model

During the Intercontinental Transport of Ozone and Precursors (ITOP) project, which was conducted in summer 2004 as part of ICARTT field study, Ravetta et al. (2007) detected with the lidar ALTO (Ancellet and Ravetta, (1998, 2003)) two BB plumes above the ground based station of the Observatoire de Haute-Provence (OHP), located in southern France [43.9° N, 5.8° E, 690 m a.s.l.] (Fig. 1). According to Lagrangian analysis based on models and aircraft measurements, the BB layers originated from forest fires in Alaska or Canada and they were transported to Europe (Petzold et al., 2007; Ravetta et al., 2007; Real et al., 2007).

For all the simulations of the aerosols radiative properties, the model MOMO (Fell and Fischer, 2001) is used, which simulates actually only the solar spectrum. It should be noticed that the model estimations for solar zenith angles (SZA) larger than about 80° are not very accurately, as MOMO supposes a plane parallel atmosphere. The software package OPAC (Hess et al., 1998) is used in order to model the optical properties of the BB aerosols and more specifically the aerosol types 'continental average' and 'urban' that are more closely to the existent ITOP results, as there is not biomass burning aerosols class in the package. Also, the surface albedo and its wavelength dependence in the solar spectrum will be based on the MERIS data (Schroeder et al., 2005; Muller et al., 2007) for the region around OHP (Fig. 2).

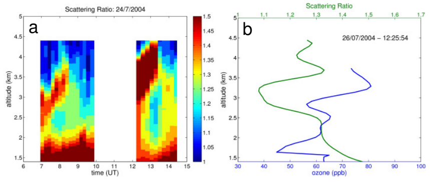

Figure 1: a) 316 nm scattering ratio of aerosols at 24 July and b) profiles of scattering ratio and ozone at 26 July, 2004.

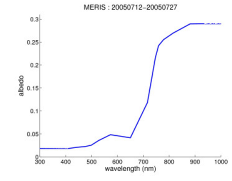

Figure 2: MERIS 412.5-885 nm albedo for the period 12 – 27 July 2005 and its extrapolation.

5. Conclusions and perspectives

The sensitivity studies have shown that the most determinant parameter is the surface albedo accompanied by the optical depth, when it is large enough (over 1) and then follows the vertical position of the layer, of which the effect can be omitted to the first order. On the contrary, the shape and the vertical extension of the layer do not seem to influence significantly the radiative properties of the aerosols, apart from the impact of extension on the heating rate.

Then, we examined the impact of BB aerosols for three profiles, which were the most important registered during the ITOP campaign. At the TOA the radiative forcing depends on the model. For the continental average model it is always negative (cooling) with instantaneous values between -11 and -1 Wm^{-2}, on the contrary for the urban model depends on the SZA (for small SZA there is warming, while for large SZA there is cooling), while it is between -6 and 6 Wm^{-2}. At the BOA, the radiative forcing is always negative (cooling), with instantaneous values down to -30 Wm^{-2} for the continental average model and -47 Wm^{-2} for the urban model. The instantaneous heating rate may reach 5.5 K/day for the continental average model and up to 8 K/day for the urban one. The mean daily values of the abovementioned radiative quantities can be found on paragraph 4.

The next step will be the estimation of the BB radiative impacts above Athens and the characterisation of their evolution not only in the Mediterranean basin, but from their first detection above North America up to Athens. This could be done for a more appropriate model describing the optical properties of BB aerosols.

References

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3. Sensitivity studies

Sensitivity studies were realised by using the two abovementioned OPAC aerosol models for two cases of relative humidity (0% and 50%), as usually the BB plumes are dry. The studies were realised for modifications of the aerosol layer characteristics like its I) vertical shape (orthogonal and Gaussian), II) its vertical position (μ=2.55, 3.35, 3.55 and 4.55 km) and III) extension (σ=0.2, 0.4 and 0.8 km) for Gaussian profile, IV) its optical depth (τ=0.01, 0.05, 0.10, 0.20, 0.50, 1.00 and 2.00 at 550 nm) and V) the change of the earth albedo (null and the double of MERIS). The examined radiative quantities are the irradiance at the top of the atmosphere (TOA) and at the surface (BOA), as well the shortwave (SW) heating rate of the atmosphere for the whole solar spectrum. More details on these sensitivities studies can be found in Tsamalis (2009). The main results are:

I) For the two shapes the relative error is very small with values lower than ±0.006% for SZA<70° at both the TOA and the BOA and for all the studied cases. Even in the case of 2 layers in the same profile the relative difference of irradiance both at the TOA and at the BOA for SZA<70° stays lower than ±0.06%.

II) For the vertical position of the layer the relative difference for SZA<70° at the TOA and at the BOA is lower than ±0.15% (Fig. 3a). The SW heating rate augments with increasing altitude, due to diminution of the air density (Fig. 3c).

III) For the layer's extension the relative error at the TOA stays always lower than ±0.07%, while at the BOA stays lower than ±0.25%. The SW heating rate varies strongly at the level of the layer, as doubling of the extension almost reduces to half the heating rate due to aerosols (Fig. 3f).

IV) For τ at the BOA there is diminution of the irradiance down to -500 Wm^{-2} (Fig. 3b), while the heating rate can reach 40-60 K/day at the aerosol layer level for SZA=0° (Fig. 3g). At the TOA, while the continental average model displays only diminution of the irradiance down to -50 Wm^{-2} (Fig. 3d), the urban model shows an increment for small SZA (up to 50 Wm^{-2}) and then a slight diminution (down to -15 Wm^{-2}) for larger SZAs (Fig. 3e). For comparison with the previous studies, the mean relative error of continental average model for τ=0.1 is -1.2% at the TOA and -3.1% at the BOA, while for τ=0.5 the respective mean values are -3.5% and -13.5%.

V) For the surface albedo large relative error up to ±11% at the TOA and up to ±24% at the BOA was observed, while its augmentation causes an increment of the SW heating rate, though not only at the level of the aerosol layer but also below it (Fig. 3h).

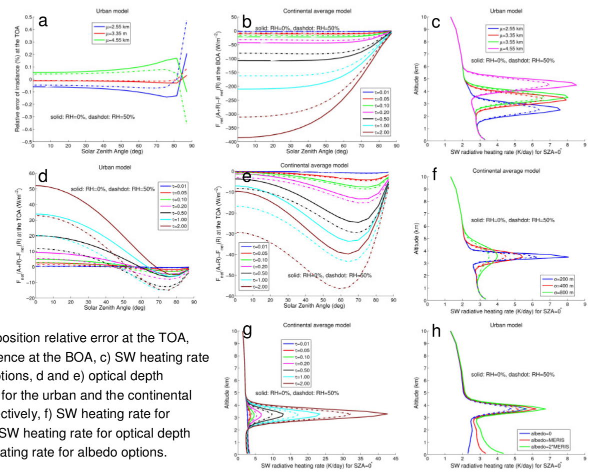

Figure 3: a) Vertical position relative error at the TOA, b) optical depth difference at the BOA, c) SW heating rate for vertical position options, d and e) optical depth difference at the TOA for the urban and the continental average model, respectively, f) SW heating rate for extension options, g) SW heating rate for optical depth options and h) SW heating rate for albedo options.