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Western african aerosols modelling with updated biomass burning emission inventories in the frame of the AMMA-IDAF program

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Abstract

African biomass burning emission inventories for gases and particles (AMMABB) have been constructed at a resolution of 1 km by 1 km with daily coverage for the 2000–2007 period. They have been evaluated using the ORISAM-TM4 global chemistry transport model, which includes a detailed aerosol module. This paper discussed comparisons between modelled results and new AMMA measurements for surface BC and OC concentrations and scattering coefficients, aerosol optical depths and single scattering albedo from sunphotometer and satellite data. Major aerosol seasonal and interannual evolution over the period 2004–2007 observed at Djougou (Benin) and Banizoumbou (Niger) AMMA/IDAF sites are well reproduced by our global model, showing the importance of using accurate biomass burning emissions. It is the first time to our knowledge that a global model treating core/shell mixing for optical calculations reproduces aerosol optical depths (AOD) values of the same order as satellite and AERONET data. Comparison of simulated and measured concentrations for different class sizes simulated by the model give information on possible refinements of the emissions, according to the particulate size fraction, which have an impact on aerosol optical properties.

1 Introduction

Western African aerosols are complex mixtures of combustion aerosols emitted from biomass burning (mainly savanna fires), domestic fires (fuelwood and charcoal), fossil fuel sources (traffic, industries), together with dust particles from the Sahel and Sahara. The temporal distribution for these sources is rather well known: open biomass burning aerosols are only produced during the dry season, domestic fires due to cooking and traffic and industrial aerosols are present during the whole year. Dust particles are also present all year long. Some contribution of secondary organic aerosol from vegetation and nitrates from soil NO_x is expected, particularly during the wet season. Both (combustion, dust and other bioaerosols) are expected to

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be within mixed aerosols. The study of such aerosol mixtures is of particular interest, because their different sizes, chemistry and optical properties result in significant radiative, climatic and health impacts (Solmon et al., 2008; Kaufman et al., 2002; Lesins et al., 2002; Myhre et al., 2003; Curtis et al., 2006; Carmichael et al., 2009, http://www.ipcc.ch/ipccreports/ar4-wg2.htm).

Before the AMMA (Multidisciplinary Analyses of African Monsoon) program (http://www.amma-international.org/), few field studies have discussed Western African aerosols. Many experiments have analyzed combustion aerosols at different periods. For example, experimental work on emissions was performed within the DECAFE (Lacaux et al., 1995) and EXPRESSO (Delmas et al., 1999) programs, studies on deposition within the IDAF (IGBP/IGAC/DEBITS in Africa) network (http://www.medias.obs-mip.fr/IDAF, Galy-Lacaux et al., 2009) and studies on radiative impact within the AERONET network (http://aeronet.gsfc.nasa.gov/). First global modelling simulations were associated with experimental works considering biomass burning aerosols together with emission inventories development (Liousse et al., 1996, 2004; Myhre et al., 2008). In parallel, dust studies have been performed over the Sahara region within national and European programs, which led to dust emissions parametrizations (Marticoréna and Bergametti, 1995). Experimental and modelling work discussing aerosol heterogeneous processes including HNO_3 and dust interactions were conducted by Galy-Lacaux et al. (2001) and Bauer et al. (2004).

AMMA is offering a unique opportunity to study Western African aerosols and their impacts, since the different participants to the project are working together on many different aerosol features, such as emissions, modelling and measurements of both dust and combustion aerosols. In AMMA, different periods of observations were considered: long term (AMMA-LOP, Long Observation Period/IDAF, 2005–2010) and short term (EOP, Enhanced Observation Period, 2005–2007) observations periods together with intensive campaigns (SOP, Special Observation Period, 2006).

This paper is focused on Western African aerosols, more specifically on combustion aerosols.

A first challenge was to develop real-time biomass burning emissions during the AMMA EOP period (2005–2007) for gases and particles. Among African sources of gases and particles, open biomass burning is a significant contributor to the chemical burden of the atmosphere. Calculating emissions from savannas, forests and agricultural fires requires the knowledge of appropriate emission factors as well as spatial and temporal distributions of burnt biomass. The first attempts to quantify burnt biomass on a regional/global scale were based on FAO (United Nations Food and Agriculture Organization) land use statistics complemented with general assumptions about percentages of burnt surfaces per year (Hao et al., 1990; Hao and Liu, 1994; Liousse et al., 1996). Recent improvements rely on real-time satellite data. Recently, Michel et al. (2005) and Stroppiana et al. (2010) have concluded that a combination of both burnt areas and active fire information derived from satellites were needed to properly account for open biomass burning emissions, together with consistent methodologies specific of regional conditions. In Africa, satellite observations of burnt areas have been shown to satisfactorily reproduce quantitative estimates of biomass burning emissions (Tansey et al. 2004; Jain et al., 2008; Stroppiana et al., 2010). Satellite burnt areas were then used to develop African biomass burning emissions for the 1980–1989 period from AVHRR data (Liousse et al., 2004) and for the year 2000 using the GBA (Global Burnt Area) 2000 product (Konaré et al., 2010). In Sect. 2, the updated methodology used to derive the AMMABB inventories is described, and corresponding results are discussed.

A second challenge was to verify if the use of these new biomass burning emissions in a global/regional transport model provides satisfactory results, when compared to experimental data (surface, satellite and integrated-column) obtained during the AMMA experiment. A study about Africa was recently performed, which considered the year 2000 (Konaré et al., 2010); the Spot-VGT 2000 (GBA2000) burnt areas products were used, together with the RegCM3 model, MODIS satellite observations and SAFARI-2000 data (Swap et al., 2002). In this paper, we will use a new chemistry-transport model and new measurements. Up to now, global models separately considered the

different aerosol components and AOD values were simply calculated by adding the effects of all components (Kinne et al., 2006, Koch et al., 2009). The new code used in the present study, ORISAM-RAD, includes the calculation of time-evolving internal mixtures of particles and ensuing optical properties (extinction, scattering and absorption) for internally core/shell mixed aerosols (Mallet et al., 2005; 2006; Péré et al., 2009). Water is included as a reactive component with on line optical properties calculations, as for the other components. A global simulation has been performed, which covers the EOP period, using the ORISAM-RAD code implemented in the TM4 global chemistry-transport model. This model includes a detailed 6-bin dynamic sectional aerosol module (Guillaume et al., 2007), with internal mixing of all aerosol components (carbonaceous aerosols, dust) and secondary particle formation (secondary organic aerosol, sulfate, nitrate, ammonium, water, sea-salt).

Our study also took advantage of the very recent AMMA aerosol measurements developed in savanna areas in the frame of the IDAF program (AMMA-LOP) (Galy et al., 2010) at a new super site, Djougou (Benin), during AMMA-EOP (2006–2007) (Serca et al., 2007 and Galy et al., 2010) and during AMMA-SOP (January and July 2006) (Pont et al., 2009). Description of this model and comparison between simulations results and measurements is presented in Sect. 3.

2 Biomass burning emissions

2.1 Methodology

Daily open global biomass burning emissions for gases (CO_2, CO, NO_x, SO_2 and VOC) and particles (Black carbon (BC) and organic carbon (OC) particles) have been specifically estimated for the AMMA campaign over the period 2000–2007, at a resolution of 1 km·1 km over Africa, from a bottom-up approach using the following relationship:

$$EM = BBv \cdot EFv$$

$$BBv = BA \cdot GLCv \cdot BDv \cdot BEv \quad (1)$$

where EM are emission estimates, and BBv, burnt biomass for each vegetation class.

BA is the Burnt Area given by the L3JRC product for the year 2000–2007 (Tansey et al., 2008) at a spatial resolution of 1 km·1 km and a daily temporal resolution. These data are derived from the Spot-Vegetation satellite. GLCv represents the percentage of each class of vegetation v present within each cell of the 0.5°·0.5° vegetation map. The GLC vegetation map (Global Land Cover, developed at JRC-Ispra (http://ies.jrc.ec.europa.eu/global-land-cover-2000) is used, since it is optimized for studies in Africa for the year 2000; it considers 17 different classes of vegetation.

BDv and BEv, respectively are the biomass densities (biomass per unit volume of space occupied by a plant in ton/ha) and burning efficiencies (fraction of biomass exposed to fire and actually consumed in fire, in %) for the different vegetation classes. An important work performed in the frame of the AMMA and GICC (Gestion et impacts du changement climatique, http://www.ecologie.gouv.fr/-GICC-.html) programs was to derive the values of BDv, BEv for each GLC vegetation class (see also Mieville et al., 2010); the description of each different GLC class is given in Table 1. This study is based on inputs from Mayaux, P., personal communication (2007) and on Michel et al. (2005) and Konaré et al. (2010).

EFv are emission factors (given in g/kg of dry matter) for gases and particles, which depend on the vegetation classes. EF values for black carbon, primary organic carbon and total organic carbon are taken from Liousse et al. (2004). Other EF values for gaseous species (CO_2, NO_x, VOCs, SO_2 ...) were selected folllowing Andreae and Merlet (2004). Table 1 synthetises values finally retained for BDv, BEv and EFv for black carbon particles.

It should be noted that a detailed comparison performed for the year 2000 between L3JRC and Landsat satellite burned area products with a 30 m·30 m spatial resolution has revealed a systematic underestimation of burned areas in the L3JRC products compared to Landsat data for the GLC3 and GLC12 vegetation classes. Consequently it is important to mention that corrections issued from this comparison, i.e. burnt areas

in GLC3 and GLC12 classes typical of west African ecosystems, respectively increased by factors of 2 and 1.67 have been implemented in this study (JRC report September 2007, Grégoire, J. M., personal communication, 2007); this specific version of the inventory is called L3JRcor in the next section.

Relative uncertainties linked to AMMABB emissions inventories (uEM) of the order of 54% are obtained from the following calculation:

$$uEM = (uBA^2 + uBD^2 + uBE^2 + uEF^2)^{1/2} \quad (2)$$

where uBA is the relative uncertainty on burnt areas: uBA=0.20 (Tansey et al., 2008), uBD, the relative uncertainty on biomass densities: uBD=0.30 (Stroppiana et al., 2009; Jain et al., 2007), uBE, the relative uncertainty on burning efficiencies: uBE=0.25 (Stroppiana et al., 2009; Jain et al., 2007) and uEF the relative uncertainty on emission factors: uEF=0.31 (Andreae and Merlet, 2001).

2.2 Results

Figure 1 displays African biomass burning emissions for black carbon particles for December 2005, January and February 2006 and June, July and August 2006. BC emissions display maximum values in December in the northern hemisphere and in July in the southern hemisphere. Minimum of BC emissions occurs in March, April and May while we can notice persistent fires in North-East Africa and Southern Africa (not shown here). In the Northern hemisphere, the maximum BC emissions are always located in Central Africa. A few hot spots can be found in Western Africa with locally higher intensities in 2005 than in 2006. Opposite variation may be noticed at the regional scale with higher BC emissions in 2006 than in 2005, as shown in Fig. 2a which presents interannual variations of yearly African BC emissions calculated for December, January and February (DJF) from 2000 to 2007. It is interesting to note that difference between maximum and minimum BC emissions for this period is in a 50% range.

Maximum African emissions (0.9 TgC/yr) are retrieved in 2000–2001, whereas minimum ones (0.6 TgC/yr) are observed in 2005–2006. Figure 2b presents interannual variations of yearly African BC emissions for June, July and August (JJA) from 2000 to 2006. As shown earlier, interannual variations are mainly due to the Southern Hemisphere fire activity. It is interesting to note that BC emissions levels are slightly higher in the southern than in the northern hemisphere. Interannual variations are less important in JJA than in the DJF period, with a maximum and minimum difference within a 30% range only. Maximum of BC emissions occurs in JJA 2006 (with 1.2 TgC/yr) instead of 2000–2001 for DJF. Minimum of BC emissions for the JJA period occurs in 2005 as for the DJF period. Among different possible causes, these interannual variations may be related to ENSO/ La Nina episodes.

Table 2 summarizes yearly African and Western/Central Africa biomass burning emissions for BC and OC for the year 2006. Data from the GFED2 inventory (Van der Werf et al., 2007) have been added for comparison. In both cases (total Africa or Western and Central Africa), we note that AMMABB estimates are higher than GFED2 ones. In order to better understand such differences, an international joint effort aimed at better identification of uncertainties in existing biomass burning inventories has been organized. It was the aim of the global intercomparison exercise INTERMEDE BBSO (see the ACCENT European Network website, http://www.accent-network.org): CO emissions derived from different satellite products were analyzed in details (Stroppiana et al., 2010). It is interesting to note that the best agreement was found for African CO emissions, with a maximum difference of about 45% for year 2003 emissions.

3 Evaluation of AMMABB emission inventories through comparison between model results and atmospheric observations

The AMMABB inventory for combustion aerosols has been evaluated using the global ORISAM-TM4 chemistry-transport model. For this purpose, simulation results using the emissions inventory described in the previous section were compared with the

recent AMMA measurements.

3.1 Model description

The ORISAM-TM4 model (Guillaume et al., 2007) is based on the coarse resolution TM4 model: TM4 is a global Chemistry-Transport Model, developed at KNMI (Royal Netherlands Meteorological Institute). It has a horizontal resolution of $3^\circ \cdot 2^\circ$ degrees in longitude and latitude, respectively and 9 vertical levels from the surface up to 40 hPa (Dentener and Crutzen, 1994; Van Velthoven and Kelder, 1996; Houweling et al., 1998). It is coupled with the ORISAM model: this is an aerosol model developed at the Laboratoire d'Aérologie (Liousse et al., 2005; Bessagnet et al., 2009). This latter model takes into account the chemistry of ozone and its precursors (Houweling et al. (1998), as well as the chemical formation of secondary organic and inorganic aerosols (secondary organic aerosol, sulfate, nitrate, ammonium, sea-salt (chlorine and sodium) and water) from gaseous precursors onto primary particles (BC, primary OC, dust), including considerations of size and microphysical aging. Thirty-eight gaseous compounds are involved in ozone chemistry and secondary aerosol formation.

In the present work, 6 classes of aerosol diameters (bins from 0.04 µm to 40 µm) are included, together with nucleation, coagulation and condensation processes. Dust and sea-salt emissions are produced following Zakey et al. (2006) and Gong et al. (2003) parametrizations, respectively. Heterogeneous chemistry on sea-salt and dust particles and aqueous chemistry are also included in the model. Aqueous chemistry for sulfate particles in cloud droplets is taken from Dentener and Crutzen (1994). Heterogeneous reactions on sea-salt are included, following Nenes et al. (1998) whereas coarse nitrate formation on dust is taken from Bauer et al. (2004) and Hodzic et al. (2006). Finally, HO_2, NO_2, N_2O_5, and NO_3 heterogeneous chemistry is based on Jacob et al. (2000). Aerosol optical properties are calculated with the RADiative (RAD) model (Mallet et al., 2005, 2006) applied to ORISAM-TM4 results, assuming a 3 layer internally mixed aerosol structure. Particle core is made of BC and dust, the first shell of primary organic carbon and the second shell of secondary aerosol species (SOA,

sulfates, nitrates . . .).

Biomass burning emissions for gases and particles are from the AMMABB inventory described in paragraph II. These emissions also account for fire injection heights. Indeed different vertical distributions are introduced in the model for savanna and forest burning following Lavoué et al. (2000). The emissions from other natural processes and resulting from anthropogenic activities are described in Guillaume et al. (2007). Natural emissions of DMS from the oceans, sulfur from volcanoes and soil NO_x are taken from the GEIA emissions portal (http://www.geiacenter.org/), NO_x produced by lightning and organic biogenic precursors (terpenes) are taken from the POET inventory (Granier et al., 2005).

Anthropogenic emissions from fossil fuels and biofuels for black and organic carbon emissions are taken from Junker and Liousse (2008). Anthropogenic emissions of gaseous compounds (SO_2, NO_x, NH_3 . . .) are from the EDGAR3.2 inventory (Olivier et al., 1999, http://www.mnp.nl/edgar/model/v32ft2000edgar/) except for CO and VOCs, which are from the POET inventory (Granier et al., 2005), and NO_x emissions are from the ANCAT 1998 database (Gardner et al., 1997). Primary sulfate emissions are estimated to be 2.5% of SO_2 emissions.

Emissions of carbonaceous aerosols are distributed onto 2 modes in the sectional model. First mode has a 0.23 µm mass diameter and the second mode (only including 20% of OC emissions) has a 2.5 µm mass diameter (Cousin et al., 2005).

Wet and dry deposition parameterizations are described in Guillaume et al. (2007). A simple parametrization to consider hydrophilic/hydrophobic fractions for BC and OC particles is used, following Cooke et al. (1999). Also wet deposition accounts for SO_2 oxidation within cloud drops and rain.

A global simulation has been performed during the whole AMMA campaign and the EOP (Enhanced Observation Period) from December 2004 to March 2007 with the ORISAM-RAD-TM4 model. ERA 40 (ECMWF) winds and precipitation fields have been introduced every 6 h from December 2004 to March 2007.

3.2 Results

3.2.1 Black carbon surface concentrations

Comparisons between modelled and experimental BC surface concentrations at AMMA/IDAF supersites are presented in Figs. 3 and 4a, respectively at Banizoumbou (Niger) from December 2004 to November 2005 (Fig. 3a), Lamto (Ivory Coast) from May 2006 to October 2006 (Fig. 3b) and Djougou (Benin) from June 2005 to March 2007 (Fig. 4a). Experimental BC concentrations at Djougou and Banizoumbou are measured using a seven-wavelength aethalometer corrected for dust interaction on absorption signal following the Fialho et al. (2008) methodology (Doumbia et al., 2009). No correction is applied to Lamto BC values obtained with a one-wavelength aethalometer. Relative uncertainty on measured BC concentrations is estimated to be of the order of 10% (Hansen et al., 1982).

Mean BC concentrations as well as BC seasonal concentrations variations are globally well reproduced by the model. At Banizoumbou, the model results overestimate the concentrations during the wet season. This could be due to uncertainties in BC deposition and transport in the global model. Even if agreements are found at Djougou between experiments and model with the L3JRCcor inventory, some modelled values are underestimated by 40–50% e.g. in December 2005 and January 2006. The use of a coarse horizontal and vertical grid resolution model to analyze observations at a specific site could explain such a difference. Moreover, experimental data issued from aethalometer analyser, are being compared to other carbonaceous aerosol measurement techniques (Galy et al., 2010). In Fig. 4a, modelled results are also given for L3JRC inventory without correction (see Sect. 2). It is interesting to note that this inventory has a very large impact on modelled BC concentrations (with a large modelled BC concentrations decrease by a factor of 6), emphasizing the importance of the corrected version of the inventory. Finally, the model satisfactorily reproduces the interannual BC variability: observed and modelled BC concentrations are higher during the 2005 than in the 2006 dry season, in agreement with local biomass burning emissions

(see Sect. 2).

3.2.2 Djougou aerosol optical properties

This section focused on a comparison between modelled and measured aerosol optical properties at Djougou. Scattering coefficients are given by a one-wavelength (0.52 µm) ECOTECH nephelometer with 10% error (Formenti et al., 2002) from February 2006 to February 2007 (Fig. 4b). Aerosol optical depths (AOD) and column-integrated single scattering albedo (SSA) are retrieved at 441 nm from sunphotometer direct and almucantar measurements (Dubovik et al., 2000) (respective error about ±0.01 (Holben et al., 1998) and ±0.03 (Dubovik et al., 2000), for AOD and SSA) from January 2005 to March 2007 (Fig. 4c,d, respectively). Experimental methods are described in Mallet et al. (2008). It should be noted that the variations in these parameters include both dust and combustion source aerosol impacts. As for BC comparisons, both scattering coefficient mean values and seasonal variations are globally well reproduced by the model.

There are two main disagreements: in June, the modelled scattering coefficients are overestimated in comparison to observations. This is mainly due to uncertainties on dust concentrations. It is interesting to note that the March 2006 dust event described by Tulet et al. (2008) and Mallet et al. (2009) is well captured by the model. A second problem occurs in January 2007, where modelled scattering coefficients are underestimated. This issue was already noticed for BC; it could be explained by local sources not taken into account in the coarse resolution model. AOD comparisons are shown in Fig. 4c, both for bulk AODc and fine particles AODf at 441 nm,: reasonable comparison is found for fine particles with lower modelled values (about 35% below observations), except for June 2006 where modelled values are 25 % higher than experimental ones. This is consistent with previous comparisons (both BC and scattering coefficients) (see Fig. 4ab). The comparison is quite different for bulk AOD. Modelled values are globally higher than observations (mean difference of 11%) with much higher model overestimates (80%) than for fine AOD (e.g. in June 2006). This is possibly due to coarse

resolution issue, which could overestimate the area of effective dust emitting regions.

Finally, Fig. 4d shows a comparison between modelled and measured single scattering albedo (SSA). Mean SSA values, as well as seasonal variations are well captured by the model. However, the differences mentioned in Fig. 4a, b and c for December 2006 and especially January 2007 (underestimates of modelled scattering coefficients and AOD) result in lower modelled SSA values (more absorption) than observed ones. It is also possible that the 100% internal core/shell mixing treatment applied in the ORISAM-RAD model tends to overestimate aerosol absorption as observed by Péré et al. (2010). Indeed, increase of the particle water uptake by high concentrations of hydrophilic aerosols could reinforce light refraction from the aerosol shell into the aerosol BC core, resulting in enhancement of particle absorption (Moffet and Prather, 2009). It is then possible that a mixture of external and internal mixing could be more realistic for African aerosols.

The comparison between observation and model results at the Banizoumbou site (not presented here) produced similar results.

3.2.3 African Aerosol chemical speciation

For the first time to our knowledge, a size-differentiated chemical speciation is implemented in a global model. The comparison with observations allows to test the aerosol components per size class and to first, study if biomass burning emissions are well distributed between all aerosol modes and second, how ageing processes impact aerosol size distribution. Fig. 5a,b display the results at Djougou for the DJF and JJA periods. The dust component, predominant in the mixture is mainly observed in the 1–40 µm size range. Modelled black carbon and primary organic carbon are maximum in the accumulation mode as well as the main part of sulfates, with maximum values found during the DJF period. Water contents, higher in summer, are mainly located in the accumulation mode. As mentioned earlier, coarse nitrate may be retrieved in coarse particles. Primary organic carbon is predominant in organic mixtures whereas secondary organic particles are only a few percent of total mass. Secondary organic particle rela-

tive abundance is higher during the wet season (vegetation peak) (7%) than during the dry season (3%). In this model version, SOA of biogenic origin is predominant.

These model results have been compared to experimental data obtained at Djougou for December 2005 and January and February 2006 period, for PM2.5 and PM10 aerosols from LOP-AMMA/IDAF and SOP data. Experimental methodology for aerosol collection and analysis is described in Galy et al. (2007) and Pont et al. (2009). Dust values are obtained from aluminium measurements and Bowen ratios (Bowen, 1966). Modelled values were obtained from Fig. 5. Figure 6 shows both modelled and experimental results on relative abundances of the main aerosol chemical species (BC, OC, dust, sulfate, nitrate and ammonium) for PM2.5 and PM10 aerosols. Both modelled or measured BC and OC concentrations are mainly included in PM2.5 aerosol. However, fine particle contribution is overestimated by the model: for example, PM2.5 BC relative contributions are 94% and 72% for the model and the measurements, respectively. Moreover, measured fine BC (72%) is more abundant than measured fine OC (60%). This is in agreement with the trend given by modelled results (94% for BC and 90% for OC) even if more pronounced in the measurements. Relative contributions from other fine and coarse species are globally in agreement between experiments and modelling.

3.2.4 Spatial distribution of Aerosol optical depth over Africa

We have compared spatial distribution of AOD values over Africa simulated by the model (right side, Fig. 7b and d) with PARASOL satellite data (http://www.icare.univ-lille1.fr/parasol/browse/, left side, Fig. 7a and c) at 860 nm for January 2006 (top) and July 2006 (bottom). It is interesting to note that modelled and measured AOD values are of the same order. This work shows that updated biomass burning emissions within a global model including a complex aerosol module with core/shell optical treatment can produce quite satisfactory results. Regional patterns given by the model are in global agreement, both in January (dry season in the Northern Hemisphere) and in July (biomass burning in the southern hemisphere), with satellite data. However there is a shift of modelled AOD maxima eastwards in January and southwestwards in July.

We have evaluated the impact of the AMMABB inventory in these shifts. In January, hot spots appear on satellite data all along the Guinean gulf, which can be explained by fossil fuel sources. Biomass burning emissions are not present at these locations (e.g. http://modis-fire.umd.edu/images/MCD45_1year_World.jpg). This shift will be then tested when regional African fossil fuel inventories will be available (Assamoi and Liousse, 2010).

The southwestwards shift obtained by the model in July 2006 could be explained by either biomass burning emission location, their transport by the model or AOD satellite data themselves. It is interesting to note that another study dealing with the influence of biomass burning from Southern Africa to Western Africa with TM4 model in July (Williams et al., 2010) shows that the model does not reproduce West- African CO and Ozone concentrations as much as the observed data suggests. A northern shift of modeled values could help to improve West African comparisons. Then, we have tested the AMMABB inventory in the regional model RegCM3 (Tummon et al., 2010). The shift observed with TM4 and ORISAM-TM4 also appears with RegCM3 model. Both regional and global models would meet a shift problem in this area. Moreover, in Tummon et al. (2010), RegCM3 model results using both AMMABB or GFED2 biomass burning inventories were compared so as to determine if the problem was due to AMMABB data. Same AOD shift exists either with GFED2 or AMMABB inventories. It is important to note that in this work, AOD comparisons are better with AMMABB than with GFED2 inventories. Finally, this shift, also seen with MODIS data (http://modis.gsfc.nasa.gov/) (not shown here) could be due to satellite data. Next generation of biomass burning inventories using both burnt areas, fire radiance energy and dynamical vegetation could contribute to understand this tricky problem.

4 Conclusions

We have developed a daily African biomass burning inventory for the 2000–2007 period at a 1kmx1km spatial resolution for gases and particles. This inventory has been

compared to other existing inventories. Differences with the GFED2 inventory are of the order of 45%, which is reasonable considering the large uncertainties remaining in the determination of biomass burning emissions (Stroppiana et al., 2010). The inventory has been tested using the ORISAM-TM4 global model for BC and OC particle emissions. Major features observed during AMMA, using both surface, column-integrated measurements and satellite data are well reproduced by the global model when updated biomass burning emissions have been implemented. Seasonal variations of modelled and measured BC concentrations are well simulated at Djougou, Lamto and Banizoumbou sites. Satisfactory comparisons are also obtained with measured surface measurements of scattering coefficients, sunphotometer AOD and column-integrated SSA values at the Djougou and Banizoumbou sites. Major problems are related to coarse model grid resolution, which is not able to catch local intense biomass burning fires and to dust modelling, which still needs further developments. Comparison with PARASOL aerosol optical depth data shows a good agreement with AOD values but displays a shift in AOD maximum. The results tend to show that an additional intense particulate source all along the Guinean gulf including megacities and industrial activities would be needed. Also, we have tested modelled BC and OC concentrations per size class allowing to see if these emissions at the source are well distributed between fine and coarse modes. Comparisons between modelled and observed IDAF/AMMA size resolved concentrations (PM2.5 and PM10) of mineral and organic species are shown to be suitable at Djougou for the December 2005, January and February 2006 period. However the model tends to favor fine particle relative contributions for BC and OC, which shows that improvements are needed in particle size determination at the source level (Janhäll et al., 2010). Other comparisons will be performed for the other IDAF sites when data will be available (Galy et al., 2010) with a finer size resolution, using the impactor data collected during the SOP experiment (Pont et al., 2010). Finally, it is interesting to note that AMMABB positive evaluation has been also obtained for gaseous components in the frame of AMMA model intercomparisons (Barret et al., 2010).

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Table 1. Correspondance between BDv, BEv and EF(BC) for each GLC vegetation classes.

GLC map	Density biomass (kg/m^2)	Combustion efficiency	EFBC (gC/km dry matter)
Broadleaf evergreen GLC1	23.35	0.25	0.7
Closed broadleaf deciduous GLC2	20	0.25	0.6
Open Broadleaf deciduous GLC3	3.3	0.4	0.62
Evergreen needleleaf forest GLC4	36.7	0.25	0.6
Deciduous needleleaf GLC5	18.9	0.25	0.6
Mixed leaf type GLC6	14	0.25	0.6
Tree Cover, regularly flooded, fresh (-brackish) GLC7	27	0.25	0.7
Tree Cover, regularly flooded, saline, (daily variation) GLC8	14	0.6	0.65
Mosaic: tree cover/other natural vegetation GLC9	10	0.35	0.61
Shrub, closed-open, evergreen GLC11	1.25	0.9	0.62
Shrub, closed-open, deciduous GLC12	3.3	0.4	0.62
Herbaceous cover, closed open GLC13	1.425	0.9	0.62
Sparse herbaceous or sparse shrub cover GLC14	0.9	0.6	0.67
Cultivated and managed areas GLC16	0.44	0.6	0.725
Mosaic: cropland/tree cover/other natural vegetation GLC17	1.1	0.8	0.64
Mosaic: cropland/shrub or grass GLC18	1	0.75	0.65

Table 2. Yearly (2006) biomass burning emission burgets for BC and OC in Africa and West and Central Africa given by this inventory and by GFED 2 inventory (Van der Werf et al., 2006, 2008) http://www.ess.uci.edu/~jranders/.

Tg species/yr	Africa (AMMABB)	Africa (GFED 2)	W. and C. Africa (AMMABB)	W. and C. Africa (GFED 2)
BC (Tg C)	2.3	0.95	0.5	0.25
OCp (Tg C)	17	7	3.3	1.8

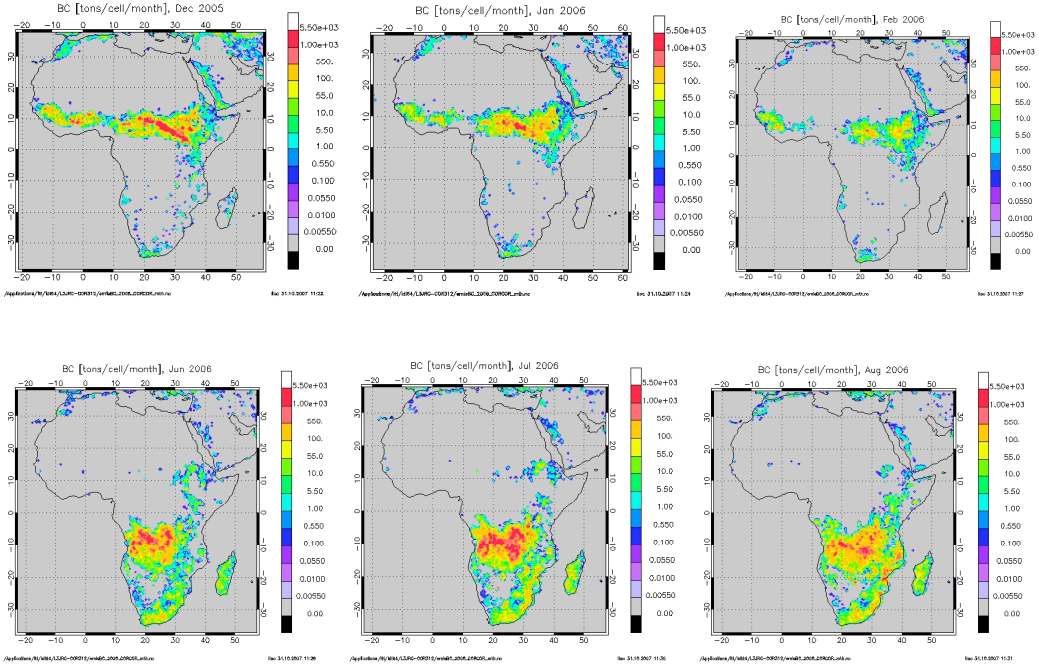

Fig. 1. Spatial distributions of BC emission inventories from December 2005, January, February, June, July and August 2006 with the new AMMABB inventory (here presented at 0.5°·0.5° resolution).

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10, 7347–7382, 2010

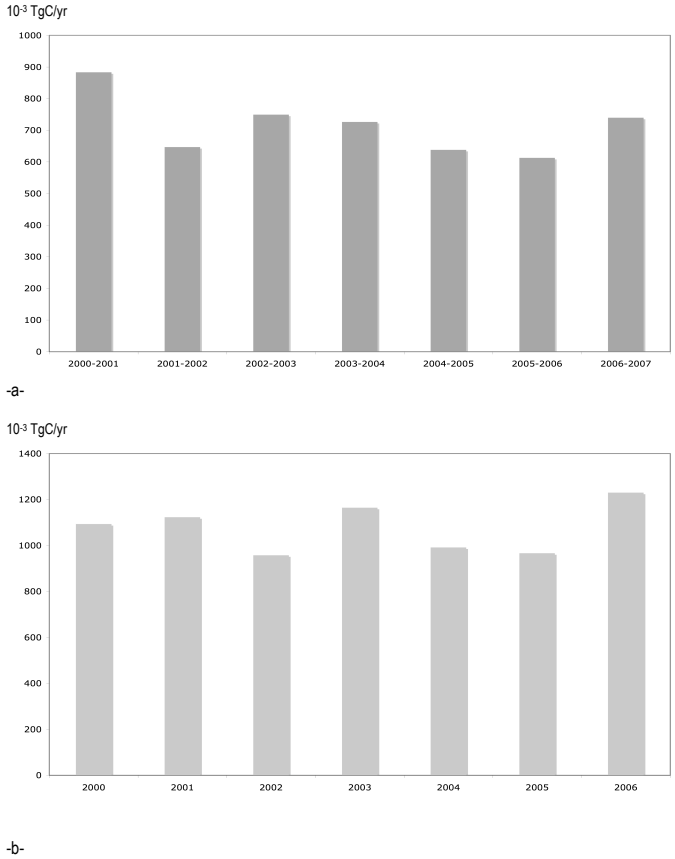

Fig. 2. African biomass burning BC emissions (10^{-3} Tg C/yr) from 2000 to 2007 for December, January and February **(a)** and June, July and August **(b)**.

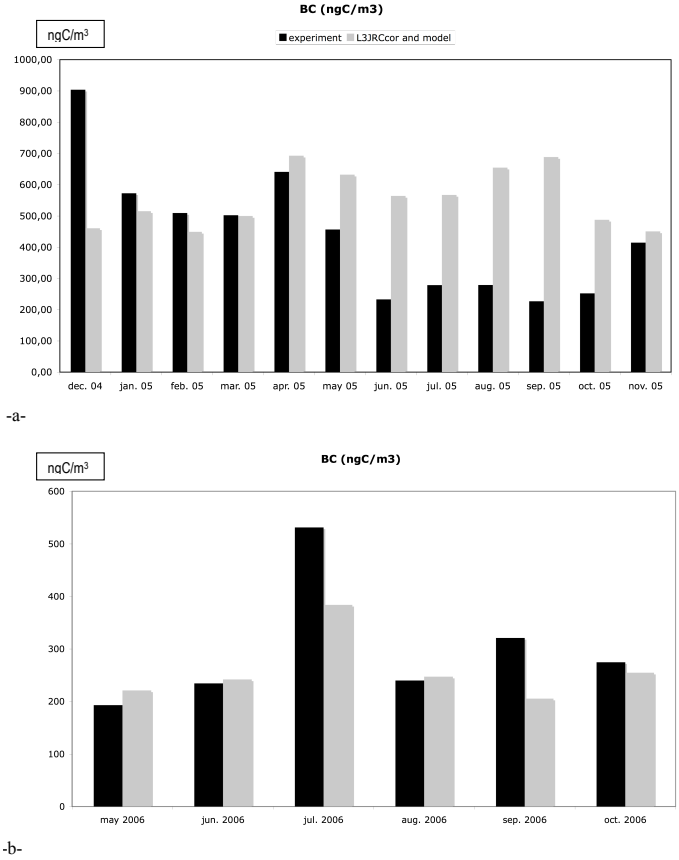

Fig. 3. Measured (IDAF/AMMA-LOP) ("experiment") and modelled (ORISAM-TM4) ("L3JRC and model") BC concentrations at Banizoumbou (Niger) and Lamto (Ivory Coast) in ngC/m^3.

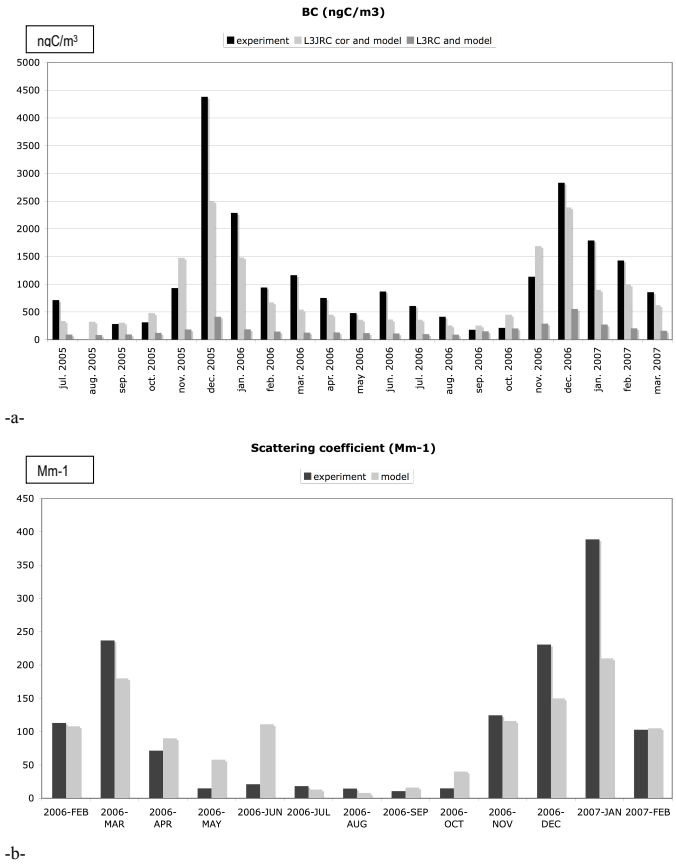

Fig. 4. Measured (AMMA-EOP, AERONET) ("experiment") and modelled (ORISAM-TM4 with different biomass burning sources) ("model") aerosol optical properties at Djougou (Benin); **(a)** BC concentrations; **(b)** scattering coefficient; **(c)** aerosol optical depth; **(d)** single scattering albedo.

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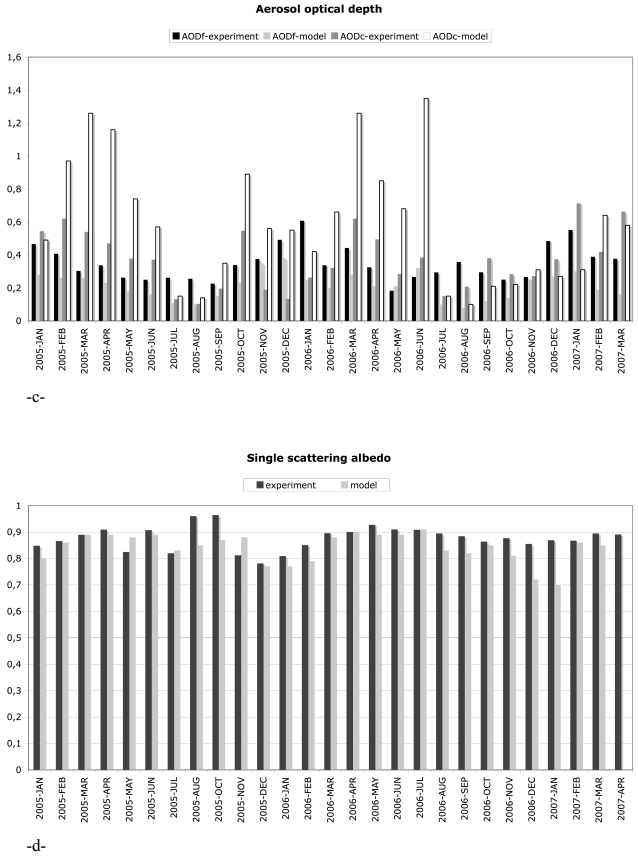

Fig. 4. Continued.

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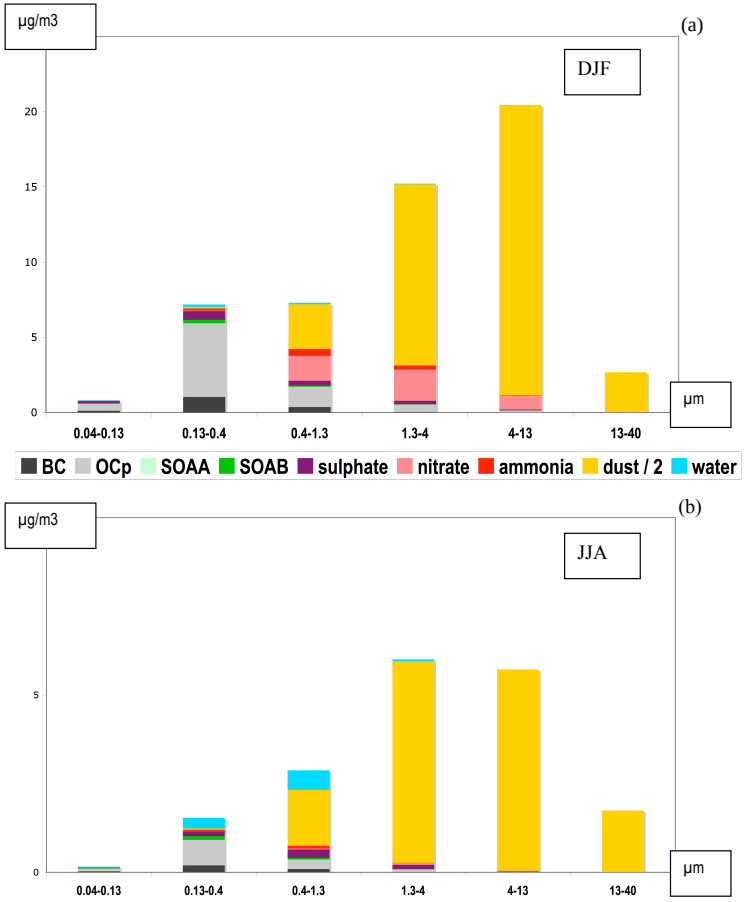

Fig. 5. Size differentiated aerosol chemical speciation from ORISAM-TM4 at Djougou (Benin) for DJF **(a)** and JJA **(b)** periods.

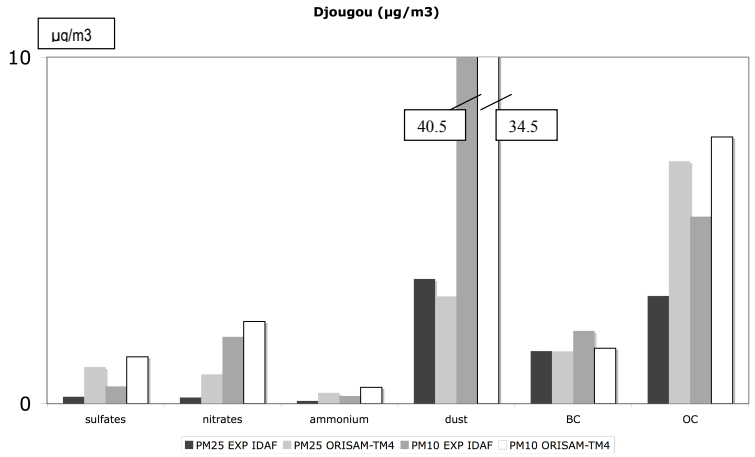

Fig. 6. Measured (EXP IDAF/AMMA-LOP-SOP) and modelled (ORISAM-TM4) PM2.5 and PM10 size differentiated aerosol chemical speciation at Djougou (Benin) for the DJF period.

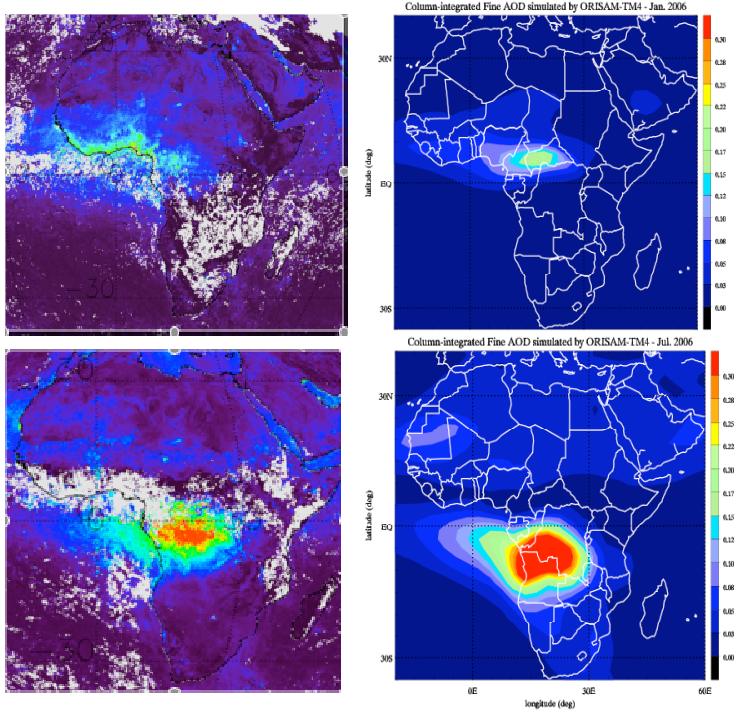

Fig. 7. Observed (PARASOL data, left) and modelled (ORISAM-TM4, right) fine aerosol optical depths over Africa in January 2006 (top) and July 2006 (down).