A review of African emissions and air quality: the need for a detailed regional inventory

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Abstract

Africa is a region with intense emissions from biomass burning, biogenic and lightning. Her present contribution to biomass burning activity remains unrivalled by any other region. The emissions of hydrocarbons by vegetation are also second only to those from South America. The combustion of fossil fuel for transport and household-use in the big cities, such as Lagos and Cairo, when co-located with the emissions from the few industries on the continent, may create an anthropogenic emissions aggregate with substantial local impact. Also elevated ozone concentrations has been seen over the continent since the late 1970s, when satellite data reported more than 45 DU of tropospheric ozone column over a large part of the continent. Model results of present-day simulations confirm that ozone concentrations are on the increase. This article provides a brief review of Africa emissions and air quality, with the aim of providing an argument and incentive for a dedicated air quality monitoring on the continent.

1. Introduction

African emissions are categorised based on their sources, and there are three broad categories, which include anthropogenic, natural and biomass burning. Anthropogenic emissions occur as a result of human activities, and are closely connected with energy-use in industry, transportation, mining, construction, and in the household. Natural sources include lightning, living plants and vegetation, soils, termites, and the digestive tracts of animals. Biomass burning also includes savanna, forest and grassland burning.

Emissions from biomass burning and natural sources are the predominant emission categories in Africa. However, rapid urbanisation occurred in some regions of Africa despite the slower industrialisation than most parts of the world, for example Lagos in Nigeria and Cairo in Egypt. Lagos population has increased from 1.7 million in 1975 to about 10.9 million in 2005, and it is projected to become the first and the eleventh most populous city in Africa and the world, respectively by 2015 (UN World Population Project 2005) with about 16 million inhabitants. This high population density resulted in high emissions from transport and household energy use (e.g. Baumbach et al., 1995). Incidentally, when the few industries on the continent are also housed by the cities, there can create an anthropogenic emissions aggregate with substantial local impact.

Biomass burning is prevalent during the dry seasons (which is late November to early March in the region of Africa north of the equator and from July to October in the southern hemispheric part of Africa (e.g. see Crutzen and Andreae, 1990 and Marenco et al., 1990), when farmers “slash and burn” agricultural waste on the farm-land. Each of these emissions categories releases carbon monoxide (CO), nitrogen oxides (NO_X=NO+NO_2), various non-methane hydrocarbons (NMHC), greenhouse gases – such as methane (CH_4) and carbon dioxide (CO_2), and a range of particulate matter.

Once in the atmosphere, some of the emitted compounds participate in the complex photochemical reactions to produce other secondary air pollutants, such as ozone and peroxy acetyl nitrate (PAN). For example increases in CO, NO_X and NMHC led to the worldwide increase in tropospheric ozone concentrations, and Africa is one of the global hot spots of high ozone concentrations (see Fig. 1). Therefore, emissions and air quality issues are highly linked. Poor air quality and especially high ozone concentrations have been shown to cause asthma attacks and pulmonary damage in humans (e.g. Peden, 2001; Desqueyroux et al., 2002; Mortimer et al., 2002), they also cause severe damage to agricultural crops including vegetation, with a potential to reduce crop yield (e.g. Mauzerall and Wang, 2001).

This article provides a brief review of African emissions and air quality issues with the aim of stressing the need for a dedicated emissions and air quality monitoring network on the African continent.

2. A brief history of emissions and air pollution monitoring in Africa

Studies on air pollution over Africa did not become popular until after the discovery of the influence of African biomass burning emissions on atmospheric trace gas constituents in the 1970s (e.g. Crutzen et al., 1979). Long before then, research on fire in Africa focused on the ecological and management aspects, with little or no thought given to the regional and global atmospheric implications of emitted trace species from fires (e.g. see Charter and Keay, 1960; Hopkins, 1963, 1965). The large-scale impact of African fires on tropospheric ozone became clear from the satellite data obtained from the Total Ozone Mapping Spectrometer (TOMS) and the Stratospheric Aerosol and Gas Experiment (SAGE) between 1979 and 1989 (Fishman and Larsen, 1987), when the tropospheric ozone column data show a well-defined maximum of ozone of more than 45DU over large part of central Africa during September and October (Fishman et al., 1990). Since then, many field experiments and campaigns have been carried out in Africa in order to quantify the enormous amount of trace species emitted in Africa and to understand their transport and impact on tropospheric chemistry. The major international field experiments on the African continent are listed in Table 1.

Table 1 – Major African campaigns and experiments conducted to understand the complex interaction of emissions (biomass burning, biogenic and aerosols) and tropospheric chemistry

Acronym	Place and Duration	References
TROPOZ[a] I	West Africa (WA), Dec. 11 – 22,1987	Jonquieres et al., (1998)
TROPOZ II	WA, Jan 9 – Feb. 1, 1991	
DECAFE	Congo, Central Africa, Feb. 1988	Fontan et al., (1992)
FOS/DECAFE[b]	Cote d'Ivoire, WA, 1991	Lacaux et al., (1995)
SAFARI-92[c]	South Africa (SA), Sept. – Oct. 1992	Lindesay et al., (1996)
TRACE-A[d]		Fishman et al., (1996)
SA'ARI-94[e]	SA, May 1994	Helas et al., (1995)
EXPRESSO[f]	Central Africa, Nov – Dec., 1996	Delmas et al., (1999)
Aerosols99	Cruise from Norfolk, Virginia (USA) to Cape town (SA), Jan. – Feb., 1999	Bates et al., (2001)
SAFARI-2000	Lusaka, Zambia. Aug – Sept. (1999, 2000)	Swap et al. (2002, 2003)
SHADOZ[g]	Nairobi and Malindi (Kenya), Irene (SA), Cotonou (Benin) (ongoing since 1998)	Thompson et al., (2003)
MOZAIC[h]	Flight to major African cities (1997-2004)	Marenco et al., (1998)
AMMA[i]	West Africa, JFM, JJA 2004 – 2007 (extended till 2009)	Redelsperger et al., (2006)

[a] TROPOZ: TROPospheric OZone experiment
[b] FOS/DECAFE: Fire Of Savannas/Dynamique Et Chimie Atmospherique en Foret Equatoriale
[c] SAFARI: Southern African Fire-Atmosphere Research Initiative
[d] TRACE-A: TRAnsport and Chemistry near the Equator - Atlantic
[e] SA'ARI: Southern African Atmosphere Research Initiative
[f] EXPRESSO: EXPeriment for REgional Sources and Sinks of Oxidants
[g] SHADOZ: Southern Hemisphere Additional OZonesondes (http://croc.gsfc.nasa.gov/shadoz/)
[h] MOZAIC: Measuremnt of Ozone and water vapour by Airbus In-service airCraft.
[i] AMMA: African Monsoon Multidisciplinary Analysis

3. The representation of African emissions in global inventories

Table 2 shows the estimate of CO and NO_X emissions from anthropogenic and biomass- burning sources as calculated by four different global inventories (EDGAR3.2, GFEDv2, POET and RETRO). The table also shows the comparison of these estimates with those used in the Intergovernmental Panel on Climate Change – Atmospheric Composition Change, the European Network of Excellence multi-model study (e.g. Stevenson et al., 2006) for the fourth Assessment report (IPCC-ACCENT AR4). The estimate shows that uncertainties exist concerning emissions. These uncertainties are closely linked with the assumptions on emission factor and other parameters used in the derivation of the emissions. For example

Jain, (2007) estimated year 2000 biomass burning CO emissions using three sets of satellite data for burned area, and found that the measured uncertainties are primarily due to the area burned data. The biomass burning emissions from POET, RETRO and GFEDv2 differ from those of EDGAR3.2 by up to a factor of 2.3 and 1.6 for global and African emissions respectively.

Table 2 shows that EDGAR and POET inventory estimated about 82 Tg/yr and 5 Tg/yr of anthropogenic CO and NOx emissions on the African continent, respectively. This agreement is due to the fact that both inventories are based on International Energy Agency (IEA) report on African energy-use, which was afterwards split into country data by using population density figures from Food And Agriculture Organization of the United Nations (FAO, http://www.fao.org/). The slight differences may be due to the assumed emission factors for different sectors. The RETRO inventory produces an estimate that is about 10 – 15% lower than the estimate from both POET and EDGAR inventories. Despite this difference in the actual amount, the inventories agree in the percentage of anthropogenic CO and NOx emissions released in Africa.

African rainforest and savannas occupy an area of about 2 million and 10 million square-km, respectively (Achard et al., 2002). Although, the rate of deforestation of virgin rainforest in Africa is about 0.43% per year (this represents 8500 square-km/yr), the results of global biogenic emissions from vegetation calculated with MEGAN (Guenther et al., 2006) which is incorporated into the general circulation model ECHAM5 (Roeckner et al., 2003) show that Africa contributes about 24% (i.e. 120 Tg(C)/yr) of isoprene and 18% (i.e. 30 Tg(C)/yr) of total terpenoids emitted globally (Aghedo, 2007a). This is because tropical plants are strong emitters of biogenic VOC.

Table 2: Year 2000 global biomass burning and anthropogenic emissions of CO (Tg/yr) and NOx (Tg/yr) as estimated in four different global inventories. Table shows the amount and percentage amount of African contributions in parenthesis.

	CO (Tg/yr)		NOx(Tg/yr)	
Inventory names	Anthropogenic	Biomass burning	Anthropogenic	Biomass burning
EDGAR3.2FT2000[a]	547.85 (82.98; 15%)	526.22 (225.25; 43%)	102.42 (5.56; 5%)	23.87 (10.59; 44%)
GFEDv2[b]	–	340.69 (183.93; 54%)	–	10.55 (6.39; 61%)
POET[c]	577.41 (81.09; 14%)	355.49 (140.06; 39%)	102.62 (5.29; 5%)	21.20 (8.40; 40%)
RETRO[d]	476.02 (67.05; 14%)	356.97 (165.57; 46%)	90.02 (3.85; 4%)	16.49 (8.58; 52%)
IPCC/ACCENT AR4*	469 (75; 16%)	506 (217; 43%)	92 (4.6; 5%)	33 (15.18; 46%)

[a] EDGAR3.2FT: Emissions Database for Global Atmospheric Research v3.2 Fast Track database, Olivier et al., 2005.

[b] GFEDv2: Global Fire Emission Database version 2. Van der Werf et al., 2006.

[c] POET: Present and future surface emissions of atmospheric compounds, Olivier et al., 2003.

[d] RETRO: REanalysis of TROpospheric emissions and composition, Schultz et al, in prep. (see http://retro.enes.org/)

Emissions a – d are available for at the GEIA/ACCENT website: http://www.aero.jussieu.fr/projet/ACCENT/database.php

* See text for explanation

4. African air quality: example of ozone and CO concentrations

Figure 1 shows the surface ozone and CO concentrations calculated in the global chemistry climate model ECHAM5-MOZ (Rast et al, in prep) for year 2000 when RETRO emissions are used. The simulation was performed in the T63L31 (i.e. 2.8 by 2.8 degrees) resolution, and the meteorology is nudged towards the ECMWF ReAnalysis data (ERA40, Simmons and Gibson, 2000).

The figure shows elevated ozone concentration of more than 40 ppbv over most part of Africa. Biomass burning has been found to be responsible for this elevated ozone, although over Nigeria, South Africa and Egypt, anthropogenic emissions can also account for up to 10 ppbv of surface ozone concentrations (Aghedo et al., 2007b). Aghedo et al., (2007b) calculated that African biomass burning, anthropogenic, lightning and biogenic emissions altogether are responsible for about 11% of the global tropospheric ozone burden (TOB) of 384 Tg (O_3)/yr, whereas they account for only 28% of 33 Tg (O3)/yr TOB found on the continent itself, which implies that import of pollutant from other continents (e.g. Europe, Duncan and Bey, 2004; and Asia, Scheeren et al. 2003) also impact Africa air quality.

5. Strategy for a systematic air quality monitoring in Africa

Despite the various internationally sponsored campaigns listed in Section 2, emissions factors and air quality data on the African continent are very sparse. Most of campaigns lasted for only few weeks, except for the ozone data collected during MOZAIC campaigns, which has been ongoing for some few years. In addition, these internationally sponsored campaigns target specific episodes of air pollution; therefore they cover few stations and sub-regions on the continent.

Moreover, most of the few measurements, which are conducted by scientists locally across the continent, found difficulty to reach the international community due to lack of information technology, efficient data sharing procedure, and high cost of publication in international journals, which forces the results to be published in local journals. Most of these local journals lack online archive system and often their printed copies lack worldwide circulation.

A meaningful systematic air quality monitoring in Africa needs to integrate the institutions and research centres (e.g. universities, and research laboratories) on the continent, and empower these institutions with air quality monitoring equipments, and the required training of students, perhaps through student exchange program. In such a way, human capacity development is ensured, and long-term air quality monitoring can be sustained. Dedicated long-term air quality monitoring on the continent is only possible and feasible when there is partnership and collaboration with scientists based in Africa. Moreover, a platform that can provide a synergy for the few air-quality monitoring sites on the continent is needed. For example, SHADOZ project coordinates and augment balloon-borne ozonesonde measurements taken on tropical and sub-tropical stations, by supporting local scientists who are actually caring out the measurement. SHADOZ also provides a contact person and website facilities for data storage and archiving, which can be downloaded free-of-charge.

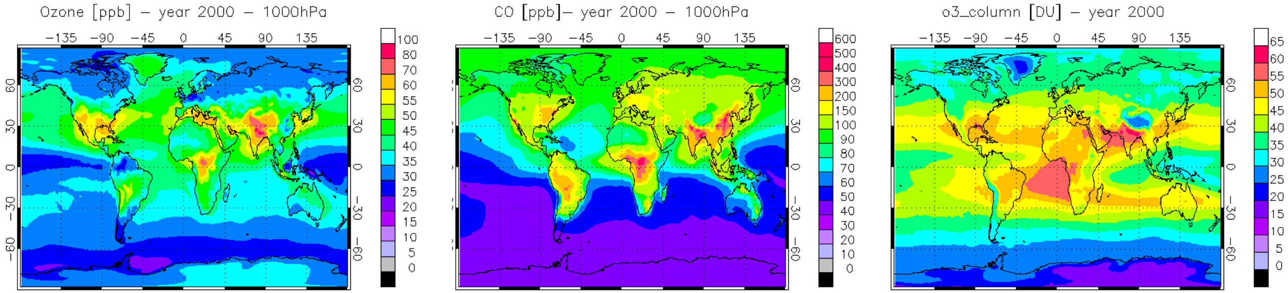

Figure 1: Year 2000 average of the surface ozone and CO concentration (in ppbv) calculated by the ECHAM5-MOZ model. The figure on the right shows the total tropospheric ozone column (in DU).

6. Conclusions and recommendation

Africa is a region with intense emissions, both from biomass burning and natural sources. Her present contribution to biomass burning activity remains unrivalled by any other region in the world. The emissions of hydrocarbons by vegetation are also second only to those from South America. Although, African anthropogenic emissions are currently much lower than those of the technologically advanced world, however, when there is co-location of the emissions from the few industries on the continent, with the combustion of fossil fuel for transport and household-use in the big cities, such as Lagos and Cairo, aggregate anthropogenic emissions may occur with substantial local impact. It is also possible that the current trend of emissions on the continent may change in the future; due to industrial advancement, transfer of old technologies from western world and continued increase in urbanization. On the other hand, biomass-burning emissions may be reduced as a result of firmer legislation on bush burning and improvement in the dissemination of information regarding health and climate implications of bush burning.

Despite this high profile emissions and air quality issues on the continent, very few air quality monitoring locations exists. There is therefore a need for a dedicated monitoring of air pollution and air quality on the continent on a long-term basis, which foster partnership and collaboration with institutions and research centres on the continent, provide a platform for the synergy of the air-quality monitoring stations already in existence, and contributes towards human-capacity development.

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