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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Tropospheric ozone over Equatorial Africa: regional aspects from the MOZAIC data" *by* B. Sauvage et al.

B. Sauvage et al.

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Response to Anonymous Referee #1

We sincerely thank Referee #1 for his/her work on this paper and the helpful comments provided in this review. They will definitely help to improve the paper, to make it clearer in the objectives and easier to read.

GENERAL COMMENTS

(a) The goal of this paper is a climatological analysis of ozone distribution, at monthly and seasonal scales. As the ozone monthly mean distributions presented in this study exhibit persistent and repetitive ozone characteristics, we wanted to further investigate connections between these characteristics and the most persistent circulation patterns in the troposphere over Equatorial Africa, such as the Harmattan, the AEJ and the Trades that have a weak variability in terms of location at monthly scale. Because high resolution transport processes or anomalies are not taken into account in this method, we will pay more attention to reformulate some of the conclusions as hypotheses. Nevertheless we aim to explain the monthly characteristics of ozone with transport processes acting at monthly scale. Concerning the discussion of flux, this section will be removed from the revised manuscript. Such a discussion will be more appropriate in the another paper (in preparation) (see answer to specific comments page S1528). (b) In the revised version, we recognize that middle and upper tropospheric ozone often have much broader geographic spread and controls. Figures 5g, 5h 5i and 5j will then be deleted. Origins will be described by words and completed with the appropriate references (TRACE-A campaign and SAFARI campaign, as also suggested p S1527, on point 3 concerning Central Africa). (c) The revised version of the paper will take into account such comments. However, the philosophy of such a climatological paper implies a presentation of the entire data set giving all the characteristics of the distribution (for every region, season, altitude range). We will avoid the repetition of detailed analyses and put an additional effort in the conclusions to make them clearer. (d) Figures will definitely be arranged. Flow patterns will be described and the understanding will be improved by adding in the introduction one panel of streamlines and 2 pictures (extreme seasons) characterizing the main transport processes in a N-S cross section (see hereafter the answer related to SPECIFIC COMMENTS 1, p S1523; available on the MOZAIC website). Figure 12 will be simply removed because the entire section 5 will be removed from the next manuscript (better appropriate for the other paper in preparation). (e) Revised text will better reflect mechanisms of ozone chemistry and we will avoid any abusive use of the term “deposition”. (f) Reference list will be surely completed (papers from the TRACE-A and SAFARI 2000 campaigns and most recent papers) (g) English will be checked once again by a native English speaker. Moreover, we would appreciate to have access to the list Referee #1 made, in order to correct alterations he noticed.

SPECIFIC COMMENTS

ACPD

4, S1778–S1786, 2004

1.Introduction.(3287:25Ě)

The wind systems that we reference in the text will be illustrated with figures of streamlines based on ECMWF mean wind fields for three levels (850, 650 and 250 hPa) and for the two opposite seasons (DJF and JJA). Moreover, we will add a scheme of a N-S cross section exhibiting the main characteristics in a vertical perspective. These figures have already been posted on the MOZAIC web site (http://www.aero.obs-mip.fr/mozaic/sauvage/papier.pdf, see Figure 1). The paragraph concerning the tropospheric ozone columns will be simply removed from the next version of the manuscript. Such considerations will be better investigated and argued in the other paper in preparation dealing with the "ozone paradox" more specifically.

2. The MOZAIC database.

2a. Database and methodology (related to comments page S1524)

MOZAIC references dealing with the definition of the program, the quality of the data, the main results obtained so far, are given. The web site is also mentioned in the manuscript for updated details and information requested by Referee#1, like the protocol access and use of data. We agree to further mention that the MOZAIC program also provide water vapor, temperature, and wind which have very high quality.

What is a climatology? From the dictionary, we would say that a climatology is a general chemical condition prevailing in an area over a long period. For the purpose of this paper, we intend to present the first in-situ data regularly recorded from the ground up to 12 km altitude over Equatorial Africa since April 1997. The richness of the MOZAIC data set allows to present a quite exhaustive catalogue of ozone profiles for the African troposphere (in terms of different seasons and altitude ranges). We may believe that such of a detailed study is particular interest for various scientific communities (other in-situ measurements, models and satellites validations, etcĚ). This way, we let people know that such data exist giving the readers a first assessment of the ozone vertical distribution for the entire year as exhibited by current Figures 3a, 3b, and 4. More-

ACPD

4, S1778–S1786, 2004

Interactive Comment

over, to really present a climatology, we aim to establish the connections with a set of descriptors, allowing a further understanding of the ozone distribution which may be expected. These descriptors are the influence of the geographical position of the fires, depending of the season; the transport processes, such as the Harmattan, Trades or AEJ; the confinement in the lower troposphere of the northern hemispheric ozone enhancementĚetc, and are written in the abstract and summary.

Concerning the statistical discussion, we will make it shorter in the revised version. Our goal was just to give proofs that the climatology we present is reliable in terms of statistics. Concerning that purpose, a preliminary cluster analysis of our data set over the Gulf of Guinea and over Brazzaville (not shown) demonstrates the robustness of our monthly means, especially during the respective burning seasons. Moreover, the paper will make clear that "meaningless means" describes a different question, which is not taken into account with monthly analyses, like the rapid temporal variation and the vertically variable plume features of ozone. This question is out of the scope of the present paper.

2b. Use of mean winds (related to comments page S1525)

As said page 3292 (paragraph starting line 18), the goal of this paper is a climatological analysis of ozone, at monthly and seasonal time scales. Then, we aim to investigate the connections between sources of pollution and various ozone enhancements measured by the MOZAIC program over a 5 years period, exhibiting characteristics on a monthly basis. To establish similar connections, many studies use seasonal winds and streamlines at constant pressure levels. Indeed, as suggested by referee#1, Jenkins and Ryu (ACP, 2004) examined the causes for low tropospheric column ozone values, by considering horizontal and vertical transport of biomass fires products, using "climatology of zonal wind and streamlines in West Africa" at 4 pressure levels (925 hPa, 700 hPa, 500 hPa and 200 hPa) at different months for the averaged years 1979-1992. Instead of using the 1997-2003 monthly means, our originality was to use such monthly analyses to compute back-trajectories, to further document the preferred pathways, and to link them to ozone monthly mean distributions, which exhibit persistent and repetitive characteristics. We definitely think that back trajectories are more reliable to establish such connections, than wind streamlines at constant pressure levels, at least in the lower troposphere. Indeed, even though back trajectories are forced with monthly mean analyses, the model is able to produce vertical motions, which is not the case with the only use of streamlines at constant pressure levels. Moreover, the monthly analyses are builded on a yearly basis, so eventual inter-annual variability is not smoothed. Besides, monthly MOZAIC means of u, v, theta and humidity, visible on Figures7, 8 and 10 of the current ACPD paper, confirm these patterns. The goal of the paper is not to make cases studies, which would have required daily analyses with high spatial and temporal resolution.

We admit that for middle and upper troposphere, above 500hPa (P$<$500hPa), monthly analyses are not so useful. As suggested by referee#1, Chatfield et al. (2004) have shown important variability of trajectories over 5-10 days, in the middle and upper troposphere of these regions. Then, Figs 5g to 5j concerning this last part will be deleted. Origins will be advanced as hypotheses concerning these upper levels (proofed with streamlines of monthly means winds), and updated with literatures showing others possible origins, as suggested by referee#1.

Then, in the revised version of the paper, it will be added the 6 streamlines at 3 different pressure levels, during the opposite January 2002 and July 2002, in the Introduction. In section 2, a paragraph will be added, showing the good reproducibility, on a statistical basis, of the main lower tropospheric transport pathways (Harmattan and AEJ in DJF, Trades in JJA). The goal is to prove that both back trajectories initialized with daily and monthly analyses characterize the same pathway, in the lower troposphere (P $>$ 500hPa). Methodology, details, figures and conclusions of this comparison has been posted on the MOZAIC web site (see http://www.aero.obs-mip.fr/mozaic/sauvage/papier.pdf). The paragraph included in section 2 of the revised version will be a summarize of the study presented on the MOZAIC website, with

ACPD

4, S1778–S1786, 2004

Interactive Comment

two figures showing comparison between back trajectories computed with daily and monthly analyses, and the Table 1 (MOZAIC website) as a summarize. We think that this work allows us to use monthly means analyses to compute back trajectories, at least in the lower troposphere. Figure 5a 5b 5e 5f will be conserved, Figure 5c and 5d will be changed with back trajectories computed with daily analyses (see http://www.aero.obs-mip.fr/mozaic/sauvage/papier.pdf for explanations), Figures 5g 5h 5i and 5j will be deleted. In this paragraph, we will also mention the limitation of the monthly analyses, which do not represent processes with short synoptic variability (3-5 days), as easterly waves, Saharan heat low, dry convection, and the limitation of the Lagrangian approach in the boundary layer, which do not take into account processes such as convection and turbulent mixing.

3. Distributions and Variability

Many comments have been written here by Referee#1. We answer below the most specific points and of course, the revised version will take into account all the comments and remarks. For example, he/she suggests quite a few references to further argue our hypotheses. We fully agree to include the missing references.

1- Gulf of Guinea. Lower troposphere

- p. 3293 background : In this paper, the term background should be understood as the following. The background is considered as being the ozone monthly mean during the less polluted season (here MAM). In this study it appears to be quite constant at about 40-50 ppbv throughout the troposphere. - p. 3294 and many succeeding pages “deposition” is often mentioned: We admit that deposition is a slow process that just operates at ground levels. We agree we made an abusive use of this term. We will pay attention to thoroughly check before including any photochemical theory in the next version. - Comments about region vs inter continental-scale will be omitted in the next version. - p. 3295: Figures shown (with transport from fires to Gulf of Guinea) will be deleted (see previous explanation). However, these figures were made with mean

ACPD

4, S1778–S1786, 2004

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Interactive Discussion

Discussion Paper

winds. With real wind, it takes only 5 days, for this southeasterly flow in JJA.

2- Gulf of Guinea. Middle troposphere As suggested, we will further mention the fact that seasonal or annual variance is smaller or not much larger than other temporal variance, for many middle and upper tropospheric parts of regions described. Indeed, please note that one of the highlighted results is the absence of any seasonal cycle in the middle troposphere over Gulf of Guinea. More over, we agree to add one sentence in the appropriate section (the one dealing with the lower troposphere over Brazzaville) to acknowledge that Edwards et al (2003) also showed a tendency for emissions in one hemisphere to loft and move to the other, during the DJF season.

Lightning remark may concern the paragraph : Middle Troposphere over Central Africa. We will mention the literature suggested by referee#1, in recasting these comments. We acknowledge that Edwards et al, 2003; Jenkins et al, 2003 & 2004; Chatfield 2003; 2004, have shown influences of atmospheric layers exposed to lightning shortly after the biomass burning ends. Moreover, we will mention the influence of air masses exposed to lightning in Northern Hemisphere and transported up to South Atlantic, as suggested by Chatfield et al., (2004).

3- Central Africa : Angola and Congo. Lower troposphere We agree to be more precise in the literature review over this particular region and propose the following changes: - At the beginning of line 11 p 3297, before “The back trajectories shown in Fig. 5eĚ”, it will be added : “This region is a much studied area. Many authors have noted recirculation over South and Central Africa (Garstang et al, 1996; Annegarn et al, 1996; Swap et al, 1996), during SAFARI campaign. Indeed anticyclonic circulation over the southern subcontinent is the dominating effect on transport processes (Garstang et al, 1996). This implies both direct and accumulating effects of fires, with gases trapped below low-level inversion, which have been described by Fuelberg et al. (1996) and with a full-chemistry simulation by Chatfield et al. (1996), during TRACE-A campaign.” - At the end of line 21 p 3297, it will be added “During austral spring, Swap et al (1996) have also observed majority easterly influence over tropical South Atlantic, with

ACPD
4, S1778–S1786, 2004

Interactive Comment

subsequent trapping of ozone by the low-level inversion"

4- Central Africa : Angola and Congo. Middle troposphere Figures 5g to 5j will be deleted and the text will be updated with the suggested literature. Lines 17Ě19 p3299 [As we can see Ě and Luanda] will be deleted, and replaced by "transport in easterly and south easterly flow from the regions of fires (Zambia, Tanzania) could bring air laden with ozone up to Brazzaville and Luanda. However, this region as well as East Africa, have complex influences, with strong seasonal and inter-seasonal controls (Chatfield et al, 2004; Martin et al, 2002). Chatfield (2004) has shown with analyses of TOMS tropospheric ozone, variable patterns running across Central Africa and into the Atlantic, with strong inflow from Indian Ocean during February-March, as previously seen by Krishnamurti (1996) in October. This inflow could bring low or high ozone, and increase background ozone between 850 and 250hPa in a few days." Lines 4Ě5 p 3300 [In Fig. 5i Ě 15°S] will be replaced: "As described during JJA, complex processes occur. Advection of biomass burning ozone precursorsĚ". Lines 18Ě 19 [Figure 5j Ě calculations] will be replaced by reference (Krishnamurti et al., 1996). "Such a transport from Brazil up to tropical South Atlantic has been modeled by Krishnamurti et al (1996)." P3301 line 7, it will we added that "another explanation of the strong such enhanced layer in the middle troposphere of Brazzaville could come from Sahel where are the fires, as Chatfield et al. (2004) observed such an origin over Ascencion Island in February."

5- East Africa. Lower troposphere Sentence " The oceanic originĚ Angola" will be changed: "Over these regions close to the Indian Ocean, south easterlies can bring clean oceanic air. Ozone values are consequently lower than those over Central Africa, where the air masses origin is mostly continental, during the same season".

6- East Africa. Middle troposphere Mean winds will just be used as hypotheses. Others origins will be updated with suggested literature like in the paragraph concerning Middle Troposphere of Central Africa.

4. Comparison with TTOC's. The goal of this section was just to present TTOCs calculations from the first regular in-situ measurements in the region. The scope of the paper was not to make a detailed comparison with the satellite data set. In this paragraph we only aimed to summarize the ozone climatology seen with the MOZAIC program in terms of tropospheric column because that is a commonly used quantity for tropical areas. We will omit that section in the revised version of the manuscript. It will be more appropriate in another paper (in preparation) dealing with other data sets like the SHADOZ network to further investigate the "Ozone Paradox".

5. Budget Computation. We will omit that section in the next version of the manuscript. It will be more appropriate in another paper (in preparation) along with the columns and the SHADOZ network data.

6. Summary and Conclusions. We thank reviewer#1 to invite us to produce a very tentatively drawn regional contour map for synthesis. However, without the conclusions from an analysis after merging MOZAIC and SHADOZ data which are expected from another paper in preparation we have, it seems to us a bit premature and subjective to do it in the present version. Work along this ides will be developed next.

Interactive comment on Atmos. Chem. Phys. Discuss., 4, 3285, 2004.