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Atmospheric Chemistry and Physics Discussions

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Interactive Comment

Interactive comment on "Space-borne observations link the tropical Atlantic ozone maximum and paradox to lightning" *by* G. S. Jenkins and J.-H. Ryu

G. S. Jenkins and J.-H. Ryu

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Response to Reviewer #1

1. The paper is qualitatively written?

RESPONSE These are the strange comments from the reviewer. What exactly does this mean? Are you suggesting that somehow the figures shown in this paper do not require any analysis? I would really like for you to be critical on the work in a very specific way rather than in a general way. Is this work flawed? Has this work been done elsewhere or is it duplication? With respect to lighting, we have quantified the various contributions from South America, West Africa and Central Africa.

In our opinion this is the first work which specifically ties lightning using observed data

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to ozone for the various seasons (DJF, MAM, JJA and SON). Edwards et al. (2003) tied lightning to elevated ozone in the Southern Hemisphere during DJF. The work of Martin et al. 2000 also tied lightning to ozone, but the NOx production was not directly tied to observed lightning data but linked to OLR. We now know that low OLR does not necessarily imply lightning (See Nesbitt et al. 2000). For example, the OLR values over South America are similar to those in West/Central Africa, but there is lot more lightning in Africa relative to South America (shown here and also in Nesbitt, 2000). In a similar way, there is more lightning over the Sahel region of West Africa but the lowest OLR values are not found there (Sealy et al. 2003)

2. The paper overlaps with paper #1.

I think that what you suggest with respect to duplication is a very serious matter. As a reviewer it is your job to point out where the duplication has occurred between the two papers. First this paper was written nearly 1.5-2 years after paper #1. The first paper, analyzes the DJF period of 1979-1992 to examine the sources of ozone and the various transport mechanisms (vertical and horizontal) and does include lightning. However, lightning is not the primary goal of paper #1. Paper #1 has a companion paper for DJF which was written specifically for the Aerosols99 campaign.

Jenkins, G.S., and J-H. Ryu, Linking horizontal and vertical transports of biomass fire emissions to the Tropical Atlantic Ozone Paradox during the Northern Hemisphere winter season: I. Climatology,[Atmospheric Chemistry and Physics Discussion, 3, 5061-5098, 2003].

Jenkins, G.S., J-H. Ryu, A.M. Thompson J. Witte, Linking horizontal and vertical transportsof biomass fire emissions to the Tropical Atlantic Ozone Paradox during the Northern Hemisphere winter season: 1999, 2003 J. Geophys. Res. 108, DOI.10.1029/2002JD003297.

We do not want to give the impression that this paper is a duplication of paper #1. This paper examines lightning specifically for Africa and South America for 1998-2001 during all seasons. It is not written specifically for DJF but gives a quantitative estimate of lightning from the two source regions and how they may relate to tropospheric column ozone.

Paper #1 was not mentioned, as it was my impression that a paper that is under review or not accepted should not be referenced. How could the reviewers have access to this other work? Anyway, it not common practice to reference work that is under review. However, we will modify the text in this paper to summarize the findings from paper #1 and also paper #2 for the DJF time period (SEE BELOW).

3. Two papers should be condensed

It is not our intention to combine these two papers. The first two papers focused primarily on DJF while this paper has the primary focus of lightning on annual timescales. Trying to merge these papers would detract from the DJF paper. We have reorganized the introduction and data sections to increase the readability of the paper.

Detailed comment.

a.) Comparison of TTO and CCD data.

We have referred the reader to the two papers that are relevant. We have also added additional material about the two different techniques in the data description section. Because the two technique are quite different it is hard to explain why the differences come about. However, the TTO data which is based on ozonesonde data for stations around the South Atlantic is in better agreement with the data from the 3 stations presented here.

b.) I donŠt know about the quality of your print version. However, the individual figures were submitted with the paper and they were full size.

c.) Figure captions do not need to mention the data source unless it has not been mentioned in the data description section.

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d.)Figures 2 and 3 are not the same thing.

While they contain the same information, the point of Fig 2 is to show how the TTO directly compares to CCD, while the point of figure 3 is to compare the distributions at each latitude zone for a particular month. Having both figures increases the readability of the paper without having the reader to struggle with text alone. Figure 3 could be removed it the editor deems it so.

e.) Figure 10/11/12/13

I donŠt have control over the final production of these figures. The full sized figures are fine, but may not look great after production. The pressure level data are fairly important in showing where ozone produced via NOx would be transported at various altitudes corresponding to these pressure levels. The focus is on the middle/upper troposphere, where lightning occurs in the tropics and where horizontal transport would presumable occur.

CHANGES TO THE TEXT

We have made changes to the Abstract, Introduction and Data methods section to increase the readability of this paper. These changes include new references and also the references to Jenkins and Ryu (2003) and Jenkins et al. (2003). We will continue to improve the readability of this text in the next two weeks.

ABSTRACT

The potential enhancement of tropospheric column ozone values over the Tropical Atlantic Ocean on a seasonal basis by lightning is investigated using satellite derived ozone data, TRMM lightning data, ozonesonde data and NCEP reanalysis during 1998-2001. Our results show that the number of lightning flashes in Africa and South America reach a maximum during September, October and November (SON). The spatial patterns of winds in combination with lightning from West Africa, Central Africa and South America is likely responsible for enriching middle/upper troposphere ozone over

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the Tropical South Atlantic during SON. Moreover, lightning flashes are high in the hemisphere opposite to biomass burning during December, January, and February (DJF) and June, July and August (JJA). This pattern leads to an enrichment of ozone in the middle/upper troposphere in the Southern Hemisphere Tropics during DJF and the Northern Hemisphere Tropics during JJA. During JJA the largest numbers of lightning flashes are observed in West Africa, enriching tropospheric column ozone to the north of 5°S in the absence of biomass burning. During DJF, lightning is concentrated in South America and Central Africa enriching tropospheric column ozone south of the Equator in the absence of biomass burning.

1. INTRODUCTION

Fishman et al. (1991) identified trends in total tropospheric column ozone (TCO) over the Tropical Atlantic using the Total Ozone Mapping Spectrometer (TOMS). They found that the highest TCO values (tropical ozone maximum) were found in Northern Hemisphere (NH) autumn (SON) primarily over the Southern Tropical Atlantic Ocean and likely associated with biomass burning in South America and Southern Africa. This feature was also found during the Transport and Atmospheric Chemistry Near the Equator-Atlantic (TRACE-A) field experiment (Fishman et al. 1996, Thompson et al. 1996). The TRACE-A observations identified regions of biomass burning and other anthropogenic sources of ozone and ozone precursors, horizontal and vertical transports of ozone/ozone precursors, and limited observations have examined the association of lightning with the production of NOx and O3 (Jacob et al. 1996). Weller et al. (1996) suggests that stratospheric intrusions of O3 may also be responsible for elevated ozone in the upper troposphere.

A feature of interest during the Northern Hemisphere (NH) winter season (DJF), is the relationship between tropospheric ozone and biomass burning. During DJF, biomass burning is confined to the Northern Hemisphere primarily in West Africa. The highest TCO values, however, are still found over the Southern Tropical Atlantic Ocean and denoted as the Tropical Ozone Paradox (Weller et al. 1996, Thompson et al. 2000;

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Martin et al. 2002; Edwards et al. 2003). In the Aerosols99 Ship campaign, Thompson et al. (2000) found the highest ozone mixing ratios in the lower troposphere downstream of biomass burning over the Northern Tropical Atlantic, but in the middle/upper troposphere over the Southern Tropical Atlantic due most likely to lightning. Edwards et al. (2003) have linked the higher TCO values of the South Tropical Atlantic to lightning from Southern Africa and South America.

Ozone enhancement in the middle/upper troposphere can occur through lightning via NOx production:

NO + HO2 –> NO2 + OH or NO + RO2 –> NO2 + RO

NO2 + hv –> O + NO

O + O2 + M –> O3 + M

Observations of NOx and O3 production associated with deep convection are limited but show that the vertical transport of ozone/ozone precursors, stratospheric intrusions, NOx and O3 production via lightning do occur (Poulida et al., 1996; Pickering et al., 1996; Stith et al., 1999; Dye et al., 1999). The study of DeCaria et al. (2000) found an ozone production of 7 ppbv d-1 from a simulated thunderstorm in the United States where elevated NOx was observed. Thompson et al. (2000) suggests an ozone production of 4-8 ppbv d-1 during the Aerosols99 campaign originating from lightning in Central Africa. Martin et al (2000) using global lightning NOx emission estimates available from Price et al. (1997) have found that lightning explains about 20% of the variance in tropospheric column ozone values of the Tropical Atlantic using EOF analysis. Using TRMM LIS data Jenkins et al. (2003) and Jenkins and Ryu (2003) have also found that lightning from Central Africa and South America likely contributes to enhancement of ozone in the Southern Hemisphere during DJF. There are also times when ozone in the upper troposphere of the Northern Hemisphere can be enhanced via convection off the coast of West Africa during DJF (Jenkins et al. 2003).

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Finding a direct relationship between lightning and enhanced tropospheric ozone is challenging because it requires the concurrent observation of lightning and tropospheric ozone. The introduction of the Optical Transient Detector (OTD) in 1995 (Christian et al. 2003) and more recently the launch of the TRMM satellite (Kummerow et al. 1998) which includes the Lightning Imaging Sensor (LIS) allowed for the mapping of tropical lightning. Techniques have also been developed to derive the tropospheric column ozone from the total column ozone from the Total Ozone Mapping Spectrometer (TOMS) instrument (Fishman et al., 1991; Hudson and Thompson, 1998; Ziemke et al. 2001). Even with these recent advances, there are still problems with the observations. For example, the LIS instrument under-samples lightning in the tropics as it takes 47 days to complete the full diurnal cycle at a particular location (Nesbitt et al. 2000). There are also problems with extracting tropospheric column ozone from total column ozone.

Kim et al. (2001) suggest that the Modified Residual (MR) technique of Hudson and Thompson (1998) can underestimate the tropospheric ozone column if high ozone mixing ratios are found in the lower troposphere. Martin et al. (2002) have suggested that satellite derived TCO values of the MR technique are underestimated by 3-5 DU over West Africa during the biomass burning season (DJF) because the highest ozone mixing ratios are confined to the lower troposphere. On the other hand, during the months of June through October, Martin et al. (2002) suggest that MR technique significantly overestimates TCO values for West Africa and the adjacent Atlantic Ocean when compared to the MOSAIC data.

The objectives of this paper are: (1) to compare monthly and seasonal TCO values over the Tropical Atlantic using TTO (using the MR technique) data and convective-cloud differential (CCD) data (Ziemke et al. 2000) during 1979-1992. (2) To examine in detail monthly and seasonal data (TCO values, ozonesondes, upper level winds and lightning) during 1998-2001. This is done in order to establish a relationship between enhanced tropospheric ozone and lightning. In particular we identify temporal/spatial

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distribution of lightning amongst South America, West Africa and Central Africa, upper levels winds and its relationship to ozonesonde measurements and TCO values over the Tropical Atlantic Ocean. (3) To examine if lightning is responsible for elevated TCO values over West Africa and the adjacent waters during JJA as suggested by TTO data. (4) To examine the relationship between the Tropical Atlantic Ozone Maximum during SON and lightning over Africa and South America. Sinks of ozone such as photolysis, deposition and chemical transformation are not explored and troposphere-stratosphere exchanges of air are also not considered.

2. DATA DESCRIPTION

The NCEP reanalysis (Kalnay et al. 1996) are used for wind at a horizontal resolution of 2.5 ° Œ 2.5°. The Tropical Tropospheric Ozone (TTO) data is based on the MR technique and produced at a horizontal resolution of 1 ° Œ 2 ° (Hudson and Thompson, 1998; Thompson and Hudson, 1999). Tropospheric column ozone values at a horizontal resolution of 5 ° Œ 5° from 1979-1992 and 1998-2001 using the cloud-slicing method (CCD) of Ziemke et al. (2001) are compared to TTO. In the MR technique, tropospheric column ozone from ozonesondes near the Atlantic Ozone Maximum is subtracted from TOMS total ozone to give the stratospheric column ozone values. Stratospheric column ozone is then subtracted from total ozone to yield tropospheric ozone at all other longitudes. In the CCD method, stratospheric ozone is set equal to the TOMS total ozone measurement over high reflecting, high altitude clouds in the western Pacific Ocean. At cloud-free pixels, with a reflectivity $<$0.2, tropospheric column ozone is obtained by subtracting the above-cloud stratospheric ozone amount from the TOMS total amount. It is assumed that highly reflecting clouds have cloud tops at the tropopause.

The ozone vertical profiles from Southern Hemisphere Additional Ozonesondes (SHADOZ) stations are also used for 1998-2000 (Thompson et al. 2003). The fire count data is estimated from the Along Tracking Scanning Radiometer (ATSR) instrument, which has a horizontal resolution of 1 km and a swath width of 512 km. Fires

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are identified at a fixed threshold of 312° K (Arino and Melinotte, 1995). The fire count data are averaged for the period of 1996-2000. Observations of non-gridded monthly lightning flashes from the Lightning Imaging Sensor (LIS) from daily overpasses are used in this study (Christian et al. 2003).

NEW REFERENCES

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