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Jean-Luc Baray, T. Randriambelo, S. Baldy, G. Ancellet. Comment on “Tropospheric O<sub>3</sub> distribution over the Indian Ocean during spring 1995 evaluated with a chemistry-climate model” by A. T. J. de Laat et al.. *Journal of Geophysical Research: Atmospheres*, 2001, 106 (D1), pp.1365-1368. 10.1029/2000JD900470 . hal-04941166

**HAL Id: hal-04941166**

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Submitted on 11 Feb 2025

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## Comment on "Tropospheric O<sub>3</sub> distribution over the Indian Ocean during spring 1995 evaluated with a chemistry-climate model" by A. T. J. de Laat et al.

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### 1. Introduction

*De Laat et al.* [1999] (hereafter referred to as L99) present a large data set obtained in the Indian Ocean during the pre-Indian Ocean Experiment (INDOEX) phase in April 1995. From an analysis of the dynamical role of upward motions of cyclone Marlene and of the tropopause fold of a subtropical jet, the consideration of outcomes from a chemistry-climate model and from backtrajectory computations, L99 infer that the enrichment of ozone observed in the upper troposphere during this precampaign mostly comes from the transport of polluted African air. L99 further attribute a contiguous tropospheric ozone minimum to the convective transport of ozone-depleted boundary layer air by the Intertropical Convergence Zone (ITCZ). An almost concomitant study *Baray et al.* [1999] (hereafter referred to as B99), based on different data, records much larger values of ozone in the upper troposphere over Reunion Island on April 6, 1995, and points to the role of subsidence induced by the cyclone Marlene in its outer environment. The purpose of this comment is to link these studies by demonstrating that some elements of L99 analysis are in close agreement with conclusions of B99, and thus further improve our understanding of dynamical mechanisms induced by tropical cyclones.

### 2. Origin of the Tropospheric Ozone Enhancement in April 1995

L99 have observed high ozone concentrations at midtropospheric levels (750-250 hPa), often in confined layers. L99 suggest that high ozone concentrations take part in midtropospheric outflow of polluted African air. Simulations for this period with the European Centre Hamburg (ECHAM) model extended with a chemistry scheme seem to give ozone increases, consistent with pre-INDOEX observations. The attribution of this

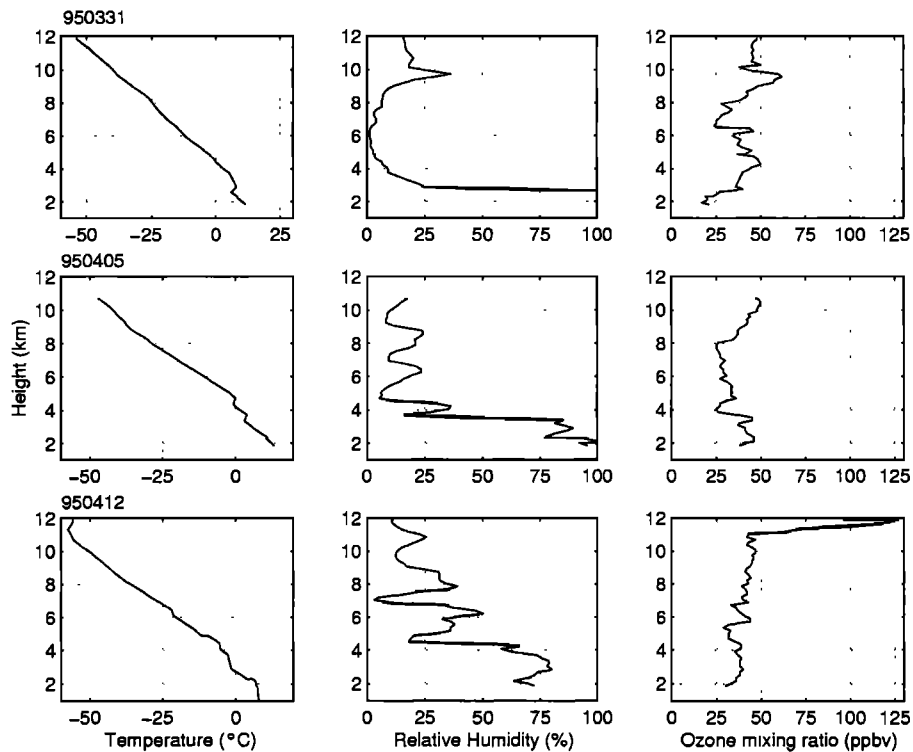
ozone enhancement to biomass burning photochemistry is based on an analysis of trajectories. L99 identify two blocks of trajectories: that of 180-270 hPa originating from biomass burning areas over Africa, and that of 380-520 hPa originating from South Africa (Figure 13 of L99). However, these trajectories are characterized by an important dispersion and indication of strong vertical wind shears, so that their interpretation is difficult in the vicinity of a tropical cyclone if one aims at separating the processes responsible for the ozone enhancement. Therefore conclusions of L99 regarding the influence of biomass burning on elevated ozone peaks should be further examined.

April coincides with the end of the rainy season in the southern subtropics. South African biomass burning and injection of ozone and ozone precursors in the free troposphere are very weak during this month. As observed from satellite platforms (National Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer NOAA-AVHRR, Defense Meteorological Satellite Program DMSP) and during field studies (Southern African Fire Atmospheric Research Initiative/Transport Atmospheric Chemistry near the Equator Atlantic SAFARI/TRACE A, Experiment for Regional Sources and Sinks of Oxidants EXPRESSO), the fire occurrences in southeastern Africa and Madagascar become significant only from September (after the dry season), peak in October-November, and then decrease rapidly in December to reach a very low level during the following months [*Cahoon et al.*, 1992; *Arino and Melinotte*, 1995; *Cooke et al.*, 1996; *Brivio and Grégoire*, 1997; *Randriambelo et al.*, 1998; *Galanter et al.*, 2000].

In contrast to the low level of biomass burning emission, the quantities of ozone observed by L99 between 13°S and the equator, and vertically between 6 and 14 km (Figure 6 of L99) are rather large, as compared, for example, with the March-to-May climatological profiles over Reunion Island presented by B99; that is, around 50 ppbv at 8 km, in comparison with 100 ppbv in April 1995 observed by L99 at 400 hPa, corresponding approximately to the same level. Furthermore, an an-

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Paper number 2000JD900470.  
0148-0227/01/2000JD900470\$09.00



**Figure 1.** Temperature, humidity, and ozone profiles obtained from Measurements of Ozone and Water Vapor by Airbus In-Service Aircraft data (MOZAIC) over Johannesburg on March 31, and on April 5 and 12, 1995.

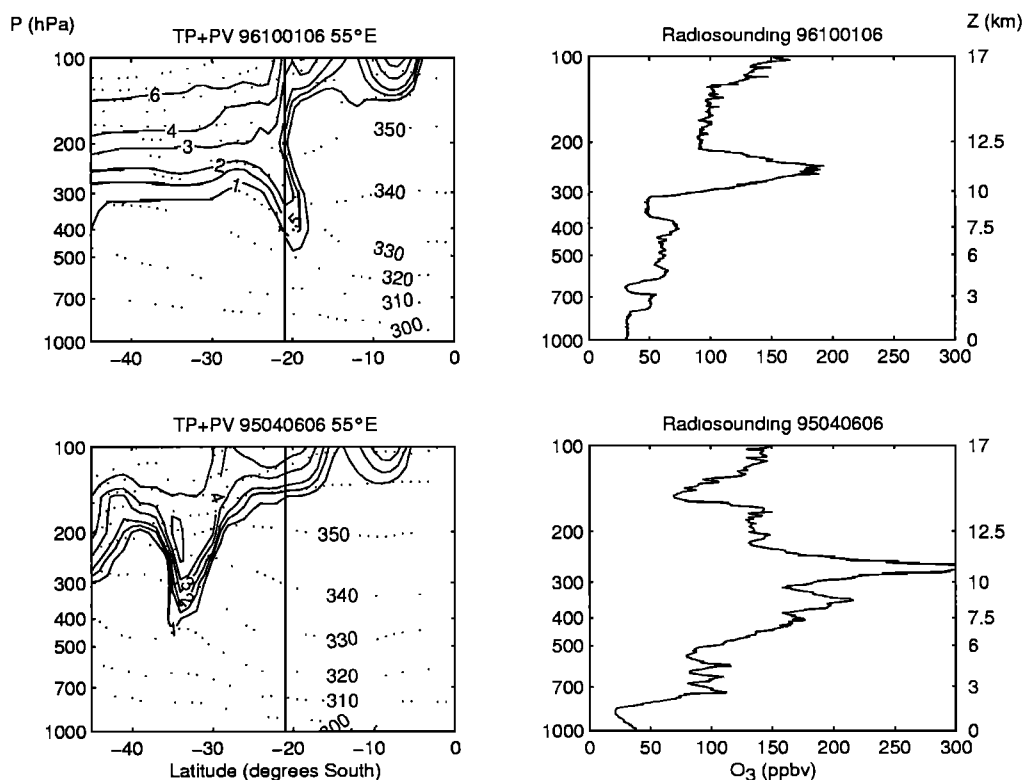
thropogenic input from southeastern Africa is contingent upon the observation of some signature of a tropospheric ozone contamination in this zone, even if some additional ozone is produced during the transport. Yet, Measurement of Ozone and Water Vapor by Airbus In-Service Aircraft (MOZAIC) data obtained from Johannesburg flights on March 31 and April 5 and 12, 1995, do not evidence any ozone enhancement (compare with Figure 1). Ozone values over Johannesburg in April 1995 are not significantly larger than the climatological ozone profile presented by B99 (compare with Figure 2b of B99). For example, at the pressure level 300 hPa, which corresponds to the 10 km height, where the contamination over the Indian Ocean is the strongest for both B99 and L99, the climatological value is 40 ppbv, and values observed in April 95 are near this value (Figure 1). These observations do not corroborate a biomass burning contamination.

Could the ozone enhancement observed by L99 originate from a tropopause fold generated by the subtropical jet stream?

The signature of the jet stream is plainly visible on Figure 6 of L99. Southward from 20°S, the tropopause is lowered to 14 km, as expected on the cyclonic side of the jet stream. Conversely, between 20°S and 10°S, the anticyclonic side of the jet stream is characterized by a tropopause lift up to 17 km. Figure 6 of L99 does not indicate a pronounced fold structure, and since the jet stream is not very intense (30 m/s) and quite

rectilinear, stratosphere-troposphere exchanges, which could occur on the cyclonic side, are not very favored. To provide a comparison with a well pronounced fold structure over Reunion Island, let us examine the case study of October 1, 1996 (Figure 2). A radiosounding was launched from Reunion, at the entrance of a very intense jet streak (70 m/s). The cross section of potential vorticity indicates a strong fold structure just over Reunion Island, and the ozone peak at 11 km height is 180 ppbv (about 100 ppbv over the climatological value), correlated with low humidity values, and a clear temperature gradient inversion (not shown). A comparison with the case of April 1995 emphasizes a very different dynamical context. The tropopause fold associated with the jet-front system is less developed (400 hPa for April 1995 against 500 hPa for October 1996), and the fold is localized at 35°S, more than 2000 km south of the tropospheric ozone enhancement observed by L99 between 13°S and 5°N. Hence the subtropical jet stream is not likely to play a significant role in this case study.

Furthermore, the combination of Figures 1 (cruise of the *Malcolm Baldrige*) and 7 (ozone profiles) of L99 suggests that the ozone enhancement is related to the cyclone Marlene and could result from downward movements occurring in the outer environment of the cyclone, in accordance with previous conclusions of B99. Indeed, the lowest values of tropospheric ozone (60 ppbv) are obtained for the more distant sonde releases



**Figure 2.** (left) Comparison of vertical cross sections of potential temperature (dotted lines) and potential vorticity (solid lines), and (right) ozone profiles obtained at Reunion Island, for two case studies: (top) October, 1, 1996, and (bottom) April, 6, 1995. The vertical black line on cross sections (left) corresponds to the Reunion Island latitude (21°S) from where radiosoundings are launched.

6, 7, and 13 from the cyclone Marlene on April 2, 4, and 11 respectively. Conversely, the nearest release (sonde 9) from the cyclone corresponds to the higher ozone values of around 100 ppbv. As the ship is moving northward and the cyclone is shifting to the southeast, tropospheric ozone is rapidly decreasing with the distance to the cyclone. This decrease is likely to be further accelerated by the simultaneous weakening of the cyclone, leading to the disappearance of ozone enhancement signature on April 11 profile (sonde 13).

Vertical ozone profiles reported by L99 and B99 are quite similar. The altitude of ozone maximum (300 hPa and 275 hPa, respectively) recorded in these two studies (L99 and B99) correspond fairly well. Further, it may be noted that the ozone peak reported by B99 is sharper and much more elevated (around 300 ppbv). Yet, owing to the tropical cyclone activity, a rapid dilution of this sharp peak is expected. Strong wind shears and turbulent mixing generated by the cyclone are likely to smooth B99 data to the L99 profile, characterized by a lower peak value and a longer horizontal spread. Strong and sharp ozone peaks, associated with elevated water vapor concentrations, have also been observed by *Suhre et al.* [1997] near deep tropical convective structures.

### 3. Concluding Remarks

A chemistry-climate model using large horizontal and vertical grids hardly catches mesoscale dynamical phenomena and is likely to underestimate cyclone-induced stratosphere-troposphere exchanges. In addition, mesoscale inertial effects and very strong wind shears generated by a cyclone could make the interpretation of air mass trajectory analysis difficult. The combination of observations reported by L99 and B99 has improved the understanding and the characterization of cyclone induced stratosphere-troposphere exchanges and tropospheric ozone enhancements in the tropics. However, mesoscale model simulations and trajectories, and high-resolution observations are needed to detail the role of downward motions associated with deep convection as already discussed by *Suhre et al.* [1997].

**Acknowledgment.** Alain Marengo (LA/CNRS Toulouse, France) is gratefully acknowledged for providing MOZAIC data used in this comment. The authors thank the LPA radiosounding team and ECMWF for providing model analyses

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(Received December 1, 1999; revised June 1, 2000; accepted August 3, 2000.)