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Interactive comment on "Ship-borne lidar measurements showing the progression of the tropical reservoir of volcanic aerosol after the June 1991 Pinatubo eruption" *by* Juan-Carlos Antuña-Marrero et al.

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"Ship-borne lidar measurements showing the progression of the tropical reservoir of volcanic aerosol after the June 1991 Pinatubo eruption" by Juan-Carlos Antuña-Marrero et al.

Answers to the Comments from Anonymous Referee # 1:

We thank the reviewer for his comments which contributed to improve the manuscript. Our answers to his comments are detailed below.

1. The uploaded data sets 3 and 4 (https://doi.pangaea.de/10.1594/PANGAEA.912780 and https://doi.pangaea.de/10.1594/PANGAEA.912781) should be renamed to aerosol backscatter coefficient (rather than aerosol backscattering ratio) to avoid confusion.

Answer: Data sets 3 and 4 were renamed to aerosol-backscatter-coefficient. https://doi.pangaea.de/10.1594/PANGAEA.912780 https://doi.pangaea.de/10.1594/PANGAEA.912781

2. Please provide a definition of the scattering ratio.

Answer: Text defining the scattering ratio and providing a reference was it was added: Page 4 Line 79:

"The single wavelength backscattering measured by a lidar is usually decomposed into two components: aerosol backscatter and molecular backscatter. The lidar scattering ratio is defined as the ratio between the total backscatter signal (aerosol and molecular) to the molecular backscatter signal (Collis and Russell, 1976)."

The added reference:

Collis, R.T.H. and P.B. Russell, Lidar Measurement of Particles and Gases by Elastic Backscattering and Differential Absorption. In Laser Monitoring of the Atmosphere, E.D. Hinkley, ed. (Springer-Verlag, NewYork 1976), p. 102, 1976.

3. It would be useful to provide a plot of the location of the measurements.

Answer: A plot with the location of the measurements was included in the manuscript, identified as "Figure 1" and a text describing it was it was added.

Page 5 Line 109:

"The trajectories of both ships are shown on Figure 1 with the positions where the lidar measurements were conducted marked with symbols. The Professor Zubov vessel (red stars) began its measurement on July 12th 1991 around 40 °N and 30 °W, trav-

elling towards the Caribbean. Upon reaching the Caribbean, near Punta de Maisí the eastern point of Cuba, by the last week of July its trajectory consisted in loop around the Antilles, except, Cuba. By early August it moved from around 20 °N and 65 °E across the Atlantic in direction to Africa reaching 10 °N and 20 ° E by the first week of September. Then it moved northeast in direction to Europe, conducting it last measurement on September 21st in the vicinity of the northern Spain. A map of the Caribbean loop trajectory is available as Supplement S2. Professor Vize measurements (blue diamonds) began at 0° longitude and -10 °N on January 26th 1991 moving northward, mainly bordering Africa and Europe ending on February 20th around 60 °N and 20 ° E."

Also the Supplement S2 (Attached) was added, consisting a map of the Caribbean Trajectory Loop describing it in detail.

4. Please use the extinction-to-backscatter (lidar) ratio in Eq. (2). A value of 25 sr is used here, probably to agree with Advyushin et al. (1991). We now know that stratospheric aerosols from volcanic eruptions have much higher lidar ratios. For instance, Prata et al. (2017, https://doi.org/10.5194/acp-17-8599-2017) find median values around 60 sr at 532 nm while CALIPSO v4 used values between 44 sr and 70 sr (Kim et al., 2018, https://doi.org/10.5194/amt-11-6107-2018). It might be worthwhile to add a brief discussion on more recent findings to put the historic data into perspective.

Answer: The complete section "3.Data Processing" is devoted to describe the processing Advyushin et al. (1991) reported they conducted. That was the algorithm we repeated to reproduce their results. That is the reason in the Eq. (2) we use the backscattering to extinction ratio, to reproduce exactly their equations and terms.

To reinforce our purpose to provide exactly the equations and terms they used we included on Page 6, line 124:

"The following is a brief description of the steps they conducted and that we followed step by step." Following the suggestion of the reviewer a brief discussion about the

magnitude of the lidar extinction-to-backscatter ratio used in this case. We clarified also the definition of extinction to backscatter lidar ratio.

Page 6 line: 146

"It is worth to mention that it is more common to use the inverse of the term among squared brackets in the former equation, denominated the extinction-to-backscatter lidar ratio. However, taking into account the goal of this work, to reproduce the up to the present unavailable data record, the language and terms used in the two cited papers has been preserved. In addition, regarding the magnitude of 0.04 sr-1 for the backscattering to extinction ratio (25 sr if the extinction-to-backscatter lidar ratio definition is used) it should be noted that for stratospheric aerosols originated from volcanic eruptions higher magnitudes have been reported (Prata et al., 2017). In particular, for the 1991 Mt Pinatubo eruption a set of vertical profiles of extinction-to-backscatter lidar ratio values from 355 to 1064 nm were produced for each month, based on size distribution fits (Jaeger et al., 1995) to balloon-borne optical particle counter measurements (Deshler et al., 1993). The conversion factors are a function of the time after the eruption and the altitude, comprising a set of wavelength exponents to convert aerosols backscatter across several wavelengths between 355 to 1064 nm, and also for aerosol extinction (Jäger and Deshler, 2002)."

The following references were added:

Deshler, T., B. J. Johnson and W. R. Rozier, 'Balloonborne measurements of Pinatubo aerosol during 1991 and 1992 at 41oN: Vertical profiles, size distribution and volatility', Geophys. Res. Lett., 20, 1435-1438, 1993.

Jäger, H., T. Deshler and D. J. Hofmann, 'Midlatitude lidar backscatter conversions based on balloonborne aerosol measurements', Geophys. Res. Lett., 22, 1727-1732, 1995.

Jäger, H. and T. Deshler, 'Lidar backscatter to extinction, mass and area con-

versions for stratospheric aerosols based on midlatitude balloon borne size distribution measurements, Geophys. Res. Lett., vol. 29, no. 19, 1929, https://doi.org/10.1029/2002GL015609, 2002.

Prata, A. T., Young, S. A., Siems, S. T., and Manton, M. J.: Lidar ratios of stratospheric volcanic ash and sulfate aerosols retrieved from CALIOP measurements, Atmos. Chem. Phys., 17, 8599–8618, https://doi.org/10.5194/acp-17-8599-2017 , 2017

5. The line marking the tropopause in Figure 1a is pink, not black. I'd also suggest to show the profiles in Figure 1 without temporal interpolation. Just as a column for each measurement time. Is it possible to unify the color bar?

Answer: The color of the line marking the tropopause was corrected in the text. The cross sections figures play a crucial role in the visual semi-quantitative validation of the reproduced results, because of the very few quantitative values cited in the two papers cited, the only source of information we have found.

To stress those facts we added the following text on Page 7, line 170:

"Both Figures are the main semi-quantitative comparison of the results we present here with those shown in Avdyushin et al. (1993), also validating our method with the few quantitative values reported in the two papers."

Because of the facts described above it is not possible to plot a profiles instead of the cross sections. The unification of the color bars will make impossible to conduct the visual semi quantitative comparison in the case of the dataset which is changed.

6. The discussion of Figure 3 and Table 2 (e.g. descending aerosol layer, decrease in layer top height) suggests a stationary measurement for which changes could be related to temporal evolution. What is shown here, however, includes the effect of the change in location. Please revise the discussion accordingly.

Answer: The discussion on the former figure 3 (now figure 4) is based in the fact that both measurements were conducted with one day of difference at exactly the same

latitude (18°N) and only 1° difference in longitude. In fact the second measurements on August 4th was conducted 1° west respect the position the day before, what at that latitude represents 110 km. Assuming are broadly known the magnitudes of the eastward wind speed in the tropics we considered unnecessary to support it.

Considering the reviewer suggestion we added the following text on Page 12 Line 244

"The former analysis was based on the assumption that the 1° difference in longitude between the positions of Professor Zubov lidar on August 3rd and 4th 1991 could be negligible compared to the magnitudes of the lower stratosphere winds transporting the stratospheric aerosols. To support that assumptions we calculated the mean northward and eastward wind components for both days in the latitude between 15 and 20 °N and the longitudes 60 to 40 °W using the NCEP Reanalysis (Kalnay et al., 1996). The figure S2 on Supplement S3 shows the profile of the lower stratosphere mean wind components for both days in the selected area around the two lidar locations. The Figure confirms the northward component was insignificant, with the dominant easterly flow at those levels in the stratosphere at that time. At the altitudes of the two aerosol extinction peaks, 19 and 23 km, the easterly wind component show values of 54 and 72 km h-1, which during the 24 h time difference measurements represent ∼1,300 and 1,700 km displacement respectively. Those displacements compare to only ∼110 km (for the 1° difference in longitude at 18 °N), supporting our assumption."

The figure S2 in the Supplement 3 is attached.

The following reference was added:

Kalnay, E., and Coauthors, The NCEP/NCAR 40-Year Reanalysis Project. Bull. Amer. Meteor. Soc., 77, 437–472, https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2, 1996.

7. There is a typo in the legend to Figure 4: Heitgh. Please also provide a description of the figure in the figure caption.

Answer: The figure 4 was replaced by a new one with the typo corrected. Because of the inclusion of the Figure showing the trajectories along what the measurements were conducted (in answer to comment # 3 former figure 4 is now figure 5.

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Supplement S2: Trajectory Loop in the Caribbean.

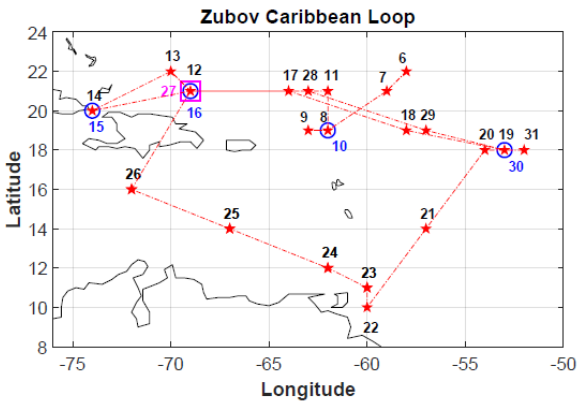

Figure S1: Professor Zubov loop trajectory in the Caribbean. The location of the measurements are identified by the red star with having nearby its consecutive order number in black. In four cases a second measurement was conducted at one of the initial locations. It was the case for measurements number 10, 15, 16 and 30, denoted by a blue circle around the red star and the number colored in blue.. In one case a third measurement was conducted at the same location the number 27, identified by a magenta square around the blue circle having the red star in the middle with the 27 in magenta.

Fig. 1. Figure S1: Zubov Caribbean Loop

Supplement S3: Mean lower stratospheric winds for August 3rd and 4th 1991.

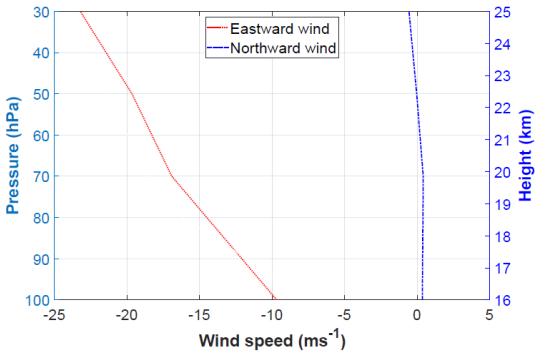

Figure S2: Mean lower stratosphere northward and eastward wind components for August 3rd and 4th 1991 in the latitude between 15 and 20 ºN and the longitudes 60 to 40 ºW using the NCEP Reanalysis data.

Fig. 2. Figure S2: Mean lower stratospheric winds for August 3rd and 4th 1991.