Response to Reviewer #1:

We thank the reviewer for his/her very useful comments and questions, which helped us improving our manuscript. Below we show the reviewer's comments in roman font and our answers italicized.

General comments

• I am concern that the results are applicable only to this particular model (AER-2D and SOCOL-AER), since other models have already found different optimizations, which might be very different from the one for SOCOL-AER (for example in Aquila et al. (2012; 2013) the best results are obtained with an SO2 injection between 16-18km). I think that this manuscript would improve and become relevant for a more general public if the authors elaborated more on what is causing the difference between model simulations. Why are particle size distributions different among simulations? Is it a matter of different relative humidity at higher or lower altitudes, or does a less broad distribution foster more coagulation? Can the life time of the stratospheric aerosol be evaluated in each case? What causes the difference in life time, the injection altitude or the faster sedimentation due to larger particles? I would also be interested in knowing more about the difference between the 2D and 3D model results. Why do the vertical profiles in Fig. 5 look so much better in the case of the 3D model? Which process is involved?

We think that our results are not "applicable only to this particular model", rather that other models that used simplified aerosol microphysics might have more uncertainty and biases. Based on the top 15 scenarios in Table 1, we obtain the location parameter μ = 20.7 ± 1.8 km, with the mean skewness α = −0.8 km. This means that the SO_2 injection peaks likely at 19.9 km with a standard error of 1.8 km, whose 95% confidence interval (16.3-23.3 km, plus or minus 1.96 standard errors) includes the results from Aquila et al. (which are in the lower range of our results). However, Aquila et al. prescribed the aerosol size distribution assuming a lognormal distribution with median radius of 0.35 µm, which is "within the range of observed values for sulfate aerosol from Mount Pinatubo". While this "within the range" might be overall a good estimate, this approximation cannot take the evolution of sizes in the months following the eruption into account. In particular, this may underestimate the size of the particles because, based on observations, the mode radius can reach over 0.5 µm during the first year after the eruption (see Figs. 2b and 3b of Bingen et al., 2004; or Fig. 4 of Russell et al., 1996). Consequently, the sedimentation of large particles in Aquila et al. is likely underestimated after the Pinatubo eruption, which might be compensated for by SO_2 injection into the lowermost stratosphere. Furthermore, as Bingen et al. (2004) state, "we expect the performances of the climatology to decrease in situations … when the coexistence of several particle modes make the choice of a monomodal size distribution inadequate". Finally, English et al. (2013) simulated the 1991 Pinatubo eruption with a vertical profile

peaking at 21 km using a size-resolving aerosol-chemistry-climate model, which is similar to the SOCOL-AER model configuration.

The above arguments highlight the importance of treating the microphysics of the stratospheric aerosol properly, which is done in our calculations. While our 2-D model approach allows us to perform very many calculations, which appear necessary to constrain the parameters of the initial volcanic plume sufficiently, it relies on prescribed winds and assumes the aerosol distribution to be sufficiently zonally symmetric. Therefore, we compared with 3-D model calculations using a free-running CCM (SOCOL) coupled with the very same microphysical module (AER) as used in the 2-D model. Our use of a CCM is similar to the approach of Aquila et al. but with coupled microphysics.

In the text, we corrected a small error, which enhanced the above disagreement with Aquila et al.: "the maximum located between 19-22 km" changed to "the maximum likely between 18-21 km". In calculating the position of the maximum we forgot to take the skewness α into account, which lowers the location of the injection maximum based on the location parameter μ. The corrected range, 18-21 km, is derived from 19.86 km plus or minus one standard error of 1.79 km.

Some more specific answers to the reviewer's questions:

-Why are particle size distributions different among simulations? *As stated above: Aquila et al. assumed a constant value, whereas AER and SOCOL-AER size distributions are computed in a coupled model.*

-Is it a matter of different relative humidity at higher or lower altitudes? *Changes in stratospheric relative humidity are small and have a negligible effect (just a few percent) on particle radius outside the polar regions.*

-Or does a less broad distribution foster more coagulation? *Yes. A less broad distribution leads to a higher number density, which in turn causes more coagulation.*

-Can the life time of the stratospheric aerosol be evaluated in each case? *Yes. We can roughly estimate the global lifetime of the stratospheric aerosol through the evolution of the global aerosol burden* (looking at its maximum and e-folding time).

-What causes the difference in life time, the injection altitude or the faster sedimentation due to larger particles? *Indeed, both affect the lifetime of the aerosol. A mass increase by 20% would cause increases in sedimentation velocities in the order 10% and lower lifetimes by 10% (if we assumed that the removal from the stratosphere of the large volcanic particles was controlled by sedimentation). Similarly, a decrease by 10% in the distance of the volcanic plume above the tropopause level, say from 20.5 km to 20.0 km, will, very roughly, also lower the lifetime by 10%. These are very rough estimates, just meant to demonstrate that both effects are important. Accurate calculations require a sophisticated coupled model.*

-Why do the vertical profiles in Fig. 5 look so much better in the case of the 3D model? Which process is involved? *The 3D model shows a better extinction vertical profile likely because the 3D model uses an improved sedimentation scheme, while the 2-D model uses an upwind scheme. See Benduhn and Lawrence (2013), Sheng et al. (2015) and Sheng et al. (Size-Resolved Stratospheric Aerosol Distributions after Pinatubo Derived from a Coupled Aerosol-Chemistry-Climate Model, submitted to JGR). Transition from 2D to 3D seems to play a lesser role (see below Figure 2).*

• It would be useful to plot Table 1 on a graph, for instance using scatter plots relating the observed and modeled values of SO2, effective radius, aerosol burden, and extinction coefficient, color coded by, for instance, SO2 injected mass and/or altitude. I would also find interesting and clear to see a Hovmöller diagram (time by latitude) of the zonal mean stratospheric AOT vs time. One of the big problems for simulations of the Pinatubo aerosol is capturing the early southward transport of the volcanic clouds, and such a diagram would show with set of parameters (especially altitude) would lead to the better result.

Here we provide an example plot (Figure 1) of the observed and modeled aerosol burden (14 Mt of SO2 injection) colored by altitudes. The figure here shows that for the 14 Mt of SO2 injection, the best agreement with the observed aerosol burden above 15 Tg can be reached by injecting SO2 near 18-19 km, while below 15 Tg can be reached near 21-22 km. Model values depend on not only the initial injection mass and altitude, but also the skewness and sigma (i.e. the vertical profile). Therefore, to plot the Table 1 requires a multi dimensional plot, which may not be useful to present all the information clearly as the scoring table already provides. So we prefer not to include such a plot.

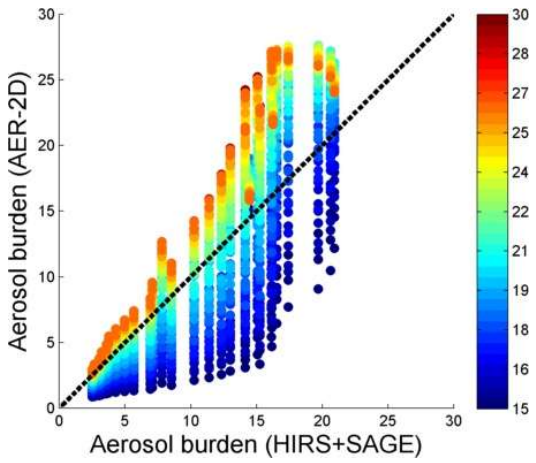

Figure 1. *Scatter plot of observed aerosol burden based on the composite of HIRS and SAGE and 2-D AER modeled values (14 Mt of SO2 injection). Color bar: altitude (km) of SO2 injection maximum.*

We added a time-latitude plot of stratospheric AOT (Fig. 6 in the revised manuscript), in which southward transport of volcanic clouds is clearly seen. We thank the reviewer for the helpful suggestion.

Specific comments:

• p4603 L20: 2006 is not very recent

We omit "recent".

• p4604 L11: With respect to which quantity was AER 2-D one of the best models? What it both for background and volcanic aerosol?

With respect to SO2, aerosol number density and extinctions under both background and volcanic conditions. We improved text accordingly.

• p4605 L20: How does SOCOL-AER simulated the stratosphere? 39 vertical layers are not many: is the stratosphere well resolved? Is the QBO included?

There are 15 levels for the stratosphere (100hPa – 1hPa). The resolution is about 1.5 km in the lower stratosphere, and about 2-3 km above 25 km. The QBO is nudged. We added the QBO information in the text.

• p4606 L6-10: It is not clear from the manuscript for how long was the SO2 injection prescribed in the model, and on which day. The authors argue for the applicability of the 2D model that the SO2 e-folding time of 25 days is comparable to the zonal transport around the globe of 25 days. From this reasoning, then the 2D model should be initialized after 20 days. However, the e-folding time marks when already 2/3 of the SO2 has been transformed into aerosol, therefore also sulfate aerosol should be included in the initialization.

The SO2 injection was prescribed on June 15-16, 1991. This is a 2D approximation. However, we see no significant differences (Figure 2 below) in the 3D simulations between a point injection and a 2D-like injection (i.e. inject SO2 into an entire latitudinal band). Therefore, we think our 2D approach is reasonable albeit the 2D limitation. The initialization of sulfate aerosol is extremely uncertain due to unknown aerosol size distributions, which might cause larger bias or errors.

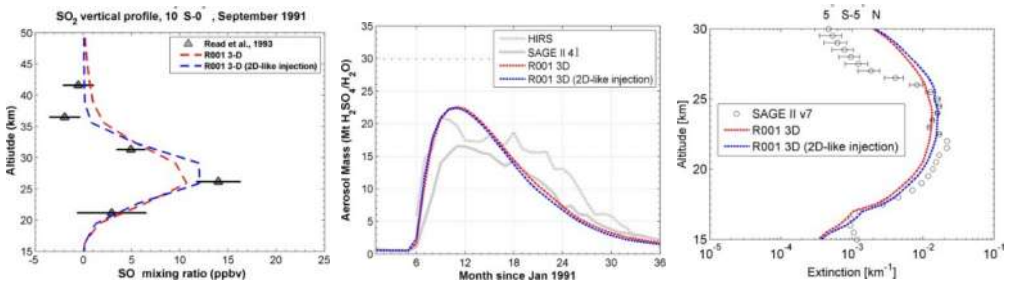

Figure 2. *SOCOL-AER 3D simulations. Comparison between a SO2 point injection (red) and a 2D-like injection (blue). Left panel: SO2 vertical profile. Middle panel: global aerosol burden. Right panel: 1020 nm extinction (5°S-5°N, Jan 1992)*

• p4608 L12: Are the authors calculating both the error in magnitude and spatial distribution? If the simulated maximum of SO2 concentration is comparable in magnitude to the observations, but slightly north than the observations, how is that calculated in this metric?

No. We only calculated the error in magnitude. We compared the model grid boxes corresponding to the location of observations.

• p4612 L22: With respect to what Is the BDC in SOCOL faster? AER-2D or observations?

"With respect to observations". We improved the text accordingly.

• p4614 L25: The overestimates in modeled extinctions are with SOCOL or with other models? I don't think that this work allows to make conclusions on other model performances.

The overestimates in modeled extinctions presented in SPARC (2006). We improved the text.