Response to RC2

In the following response, reviewer comments are in black and author responses are in blue.

Review of Lidar ratios of stratospheric volcanic ash and sulfate aerosols retrieved from CALIOP measurements by Prata et al. (2017).

Volcanic aerosol optical depth from satellites are used in numerical simulations, including those presented in the Intergovernmental Panel on Climate Change reports, to assess the impact of volcanic eruptions in climate and separate natural and anthropogenic climate forcing factors. In order to derive this quantity, native backscatter measurements from CALIOP need to be converted into an extinction coefficient using a lidar ratio. The volcanic layer detection approach of this paper is based upon the combined use of AIRS and CALIOP, providing complementary information on volcanic clouds. They calculated statistical parameters associated with the optical properties (lidar ratio, volume depolarization and attenuated color ratio) of three volcanic plumes (Sarychev, Kasatochi and Cordon) based upon the CALIOP level 2 products. They provided a thoughtful assessment of these coefficients associated with a rigorous and clear analysis of the different sources of errors. This is a very well written paper on which I dont have major comments. Thus, I strongly recommend it for publication in ACP.

I have two minor comments:
1) I believe that the proposed threshold (fig 9) to separate volcanic clouds into ash-rich and sulfate-rich categories is optimized for those cases. Indeed, Vernier et al. (2015) has shown that the pdf of the particulate depolarization ratio associated with the Kelud plume observations were indeed between those of Cordon and Sarychev/Kasatochi. Thus, the classification of volcanic cloud based upon their optical properties is challenging since those properties evolve with time depending of the presence of ash and sulfate which can also be mixed. Overall, because volcanic plumes are a mixture of two types of aerosol (external and possibly internally mixed) (sulfate and ash) which evolve with time, it makes them difficult to classify them (e.g. Kelud, Tavurvur). 2) How would you propose to use the lidar ratios calculated in this paper for deriving times series of volcanic aerosol optical depth during the months following those eruption when AIRS is not sensitive enough to detect SO2 or Ash in contrast to the CALIOP lidar measurements? I think it would be interesting to discuss how your results can be used to derive volcanic aerosol time series.
Very nice paper!

Response:
The authors thank the reviewer for their thoughtful comments on the manuscript. Response to 1) The authors agree that the proposed threshold is optimised for the case studies considered. However, as we attempted to separate ash-rich layers (AI $\geq$ 1 K and SI $<$ 1 K) and sulfate-rich layers (AI $<$ 1 K and SI $\geq$ 1 K) using AIRS, we expect that the majority of mixed layers (sulfate/ash) would exhibit an AI $>$ 1 K and SI $>$ 1 K and so would have been removed from our analysis. Our depolarization measurement results, therefore, highlight the two extreme cases (i.e. ash-rich or sulfate-rich) and so, as the reviewer has stated, values falling between the Puyehue and Kasatochi/Sarychev values would likely be a mixture of sulfate and ash (e.g. Vernier et al., 2016). Classification of volcanic aerosols into ash-rich and sulfate-rich layers is important as the lidar ratio may change depending on the composition of the layers. We approached this problem with the operational extinction retrieval in mind; when the lidar ratio cannot be retrieved directly, the aerosol must be classified as a predefined type (associated with a predefined lidar ratio). We have proposed a method for detection, using native CALIOP measurements, of sulfates and ash and have given values of the lidar ratio for

these particular case studies. We have acknowledged the reviewers point in the revised manuscript as follows:

"We also note that the suggested δ_v threshold will be optimised for the eruption case studies considered here. As volcanic aerosols are often composed of a complex mixture of both ash and sulfate, which changes with time, strict classification using a single threshold is challenging. In the case of ambiguous depolarization ratios ($\delta_v \sim 0.2$), supplementary information from collocated AIRS measurements may provide more insight into the likely composition of stratospheric volcanic aerosol layers."

Response to 2) This is the reason we explored the use of CALIOP-measured parameters for discriminating volcanic ash from sulfate after first identifying ash-rich and sulfate-rich layers using independent detection from AIRS. The depolarization ratio appears to be the most appropriate parameter for determining whether a stratospheric volcanic layer is sulfate-rich or ash-rich. As we have shown, the lidar ratio varies with time and so the assumption of a constant lidar ratio will likely introduce errors in the retrieval of extinction profiles. Optimum results for a volcanic aerosol optical depth time series would therefore be obtained by following the method presented here and only accepting cases where an extinction retrieval is constrained by an estimate of the two-way transmittance (i.e. QC_flag = 1). This would most likely restrict observations to nighttime measurements of layers with optical depths > 0.2 (see Fig. 4 of original manuscript). In cases where the two-way transmittance method fails, a predefined lidar ratio would have to be used. One could use the the PDFs presented in Fig. 2 of the original manuscript to constrain the choice of the lidar ratio. As the PDFs for the lidar ratios are positively skewed, we suggest using the median lidar ratios for this approach. For example, 60 sr for sulfate-rich ($\delta_v < 0.2$) and 67 sr for ash-rich ($\delta_v > 0.2$) layers. We have included this discussion as a subsection of Section 6 of the revised manuscript.

References

Vernier, J.-P., Fairlie, T. D., Deshler, T., Natarajan, M., Knepp, T., Foster, K., Weinhold, F. G., Bedka, K. M., Thomason, L., and Trepte, C.: In situ and space-based observations of the Kelud volcanic plume: The persistence of ash in the lower stratosphere, J. Geophys. Res. Atmos., 2016.