1 Reply to Anonymous Referee #2

Thank you for the helpful comments. We think the suggestions on figures/explanations make for a much clearer and more thorough paper.

- When describing the simplicity of the occultation technique, it would be helpful to note that (in the case of SAGE, and probably other occultation instruments as well) the aerosol extinction is computed as a residual: The extinction due to Rayleigh scattering and all gaseous absorbers is estimated first, and any remaining signal is treated as aerosol extinction. This procedure clearly allows errors from a variety of sources to accumulate in the aerosol extinction estimate, complicating the interpretation of the aerosol retrieval.

  Agreed, we will include a brief discussion of this in the revision.

- Page 5069, text prior to equation (3): Presumably the modeled Rayleigh signal is calculated for the same viewing geometry as the measured radiance, using an assumed atmosphere that contains no aerosol?

  Yes, we will clarify this in the text.

- Pages 5071-5072: The result shown in Figure 2 and the accompanying analysis seem surprising to me: The extinction ratio is said to differ most (between ascending and descending node observations) for the tropics at 25–28 km, with much lower bias for higher latitudes and lower altitudes. I would like to see the variation with altitude and latitude quantified, and also discussed further. For example, your result presumably means that the assumed aerosol microphysical properties are most correct at 25–28 km in the tropics. How low are the lower altitudes considered? Do you look into the upper troposphere / lower stratosphere (UT/LS) region? Such a simple, static model of aerosol microphysical properties seems less likely to resemble the true atmospheric conditions in the UT/LS region, or in higher-latitude regions where tropopause folds, etc. appear in the 10–20 km altitude range. Can you comment on this issue further?

  Additional plots are included below (Fig 1 and 2) to show the difference as a function of latitude/altitude, but the general reasons for the tropics at 25–28 km showing the worst agreement with respect to extinction measurements are:

  1. *The OSIRIS scattering angles have the largest separation in the tropics due to the Odin orbit.*
  2. *Low stratospheric altitudes have higher contributions of multiple scattering, helping to minimize the effects of incorrect phase functions.*
  3. *High altitudes and latitudes likely have particle sizes more similar to the assumed particle size of 0.08μm mode radius and 1.6 mode width as this distribution was based on the mid-latitude Deshler (2003) measurements.*

  Retrievals are performed in UT/LS region, however due to the frequent presence of clouds which are unlikely to conform to the particle microphysics assumptions, aerosol retrievals below the the tropopause are typically discarded. Similarly, lower stratospheric measurements which contain large cloud fractions or enhanced aerosol will saturate the IR detector, and in this case retrievals at these altitudes are not attempted. The updated figures and an expanded discussion will be included in the revised paper.

- Page 5072, 1st paragraph: It would be helpful to present the 470 nm measurement vector kernels in Figure 4, to illustrate the point that you make in this paragraph.

  This is actually easiest to see by modelling the measurement vectors as a function of mode radius and mode width. Shown in figure 3 below, are both normalized (by 470 nm wavelength) and unnormalized measurement vectors for a variety of simulated conditions. The first panel shows the change in measurement vector as a function of extinction - normalization scales the measurement, but does not substantially change the shape. Panel 2 shows the measurement vectors as the mode radius is changed. With normalization the response to small particles is fairly flat with a shallow minimum near mode radii of 200 nm. Unnormalized the measurement consistently decreases until mode radii of near 300 nm. Similarly in panel 3, the unnormalized measurement vector consistently decreases with mode width, while the normalized measurement vector has a more variable response. The consistency of the unnormalized measurements reduces the chances of falling into a local minimum when searching the parameter space. This will be included in the revised manuscript.

- Page 5077, equation (14): The atmospheric state vector x should be defined clearly, since this symbol was used earlier in equation (5) with a different definition.

  Yes, this will be clarified.

- Pages 5078-5079: First sentence should read measurement errors for the optical spectrograph and infrared imager are quite different...

  Also, how does the timing of the optical spectrograph observation (taken sequentially at numerous tangent heights) compare to the timing of the 30 or more infrared imager observations that are averaged together? Im concerned that systematic effects (such as changes of the underlying scene) should affect the two observations differently, but that possible error source is not mentioned in the text.

  The optical spectrograph takes approximately 90 seconds to perform a vertical scan, with the tangent point travelling several hundred kilometers during this time. While scanning, the infrared imager is continuously taking images. All images used in the average are taken during the scan, and so the sampled atmosphere is largely the same between the OS and IR profiles. The effects of the spherical symmetry assumptions are thus not expected to be much larger when comparing IR to OS data, than when comparing OS data of different altitudes. The precise magnitude of these errors have not been well categorized, largely due to the difficulty of modelling truly 3 dimensional atmospheres with varying ground and clouds. Oikarinen (2002) provided some estimates on errors due to changes in the underlying scene, with typical errors less than 2% at 500 nm with little to no systematic effect. However more studies are certainly needed to apply this analysis to the quantities retrieved here.

- Pages 5082-5083: Could you include some references to support attributing the change in retrieval accuracy to the Mt. Manam eruption?

  Yes, the eruption and subsequent stratospheric intrusions were noted in Tupper et al. (2007) and Vernier et al. (2011). These will be included.

- Page 5084: Can you flesh out the statement that While the wavelength difference accounts for much of the discrepancy some is likely due to the particle size assumptions? These could (and should) be estimated, based upon the assumptions that are made for aerosol microphysics.

  Some estimates were derived in Sec. 4.5, which simulated retrievals with incorrect particle size assumptions. These typically produced Angstrom coefficients within 20% of the true state, so is likely a reasonable estimate of the error. As can be seen in Figure 6 (attached here) the OSIRIS wavelengths typically produce an Ångström coefficient that is between 0.5 to 0.75 larger than the SAGE wavelengths for mode widths of 1.6. These differences vary somewhat with mode width, however are usually between 0.5 and 1. We will add this figure to the revised manuscript.

- Table 1: These criteria are used for both mode radius and aerosol extinction, correct? In that case, some clarification is required (units, what is done when convergence requirements are met for one parameter, but not the other, etc.).

  The convergence criteria were reported erroneously. In fact, only the mean squared residual and iteration limit are checked. If either is exceeded the retrieval is stopped, this will be updated in the revisions.

- Figure 3: Adding a percentage difference plot of y would improve this figure.

  Agreed, we have updated the figure in the manuscript and included the revised version as Figure 4 here.

- Figure 7: Relative errors (rather than absolute errors) would be much easier to interpret, especially in the case of extinction.

  We have updated the figure in the manuscript to show relative errors. The updated figure is attached here as 7

- Figures 9 and 10: I would like to see the geographic locations of the SAGE / OSIRIS coincidences. Based on the information given, it is difficult to reconcile Figure 9 (showing that Version 6 improves the retrieval relative to Version 5) with Figure 10 (showing little / no improvement for Version 6 relative to Version 5).

Geographic locations of the coincident measurements have been added and are shown in figure 5 below. The coincidences occur at mid-to-high-latitudes, which as can be seen in Figure 1 and 2 below, is the region where the smallest problems in extinction appear to occur. This figure and an expanded explanation will be included in the revisions.

2 References

Oikarinen, L., Effect of surface albedo variations on UV-visible limb-scattering measurements of the atmosphere, J. Geophys. Res., 107(D19), 4404, doi:10.1029/2001JD001492, 2002.

Vernier, J.-P., et al. (2011), Major influence of tropical volcanic eruptions on the stratospheric aerosol layer during the last decade, Geophys. Res. Lett., 38, L12807, doi:10.1029/2011GL047563.

Tupper, Andrew, Ima Itikarai, Michael Richards, Fred Prata, Simon Carn, Daniel Rosenfeld, 2007: Facing the Challenges of the International Airways Volcano Watch: The 2004/05 Eruptions of Manam, Papua New Guinea. Wea. Forecasting, 22, 175191. doi: http://dx.doi.org/10.1175/WAF974.1

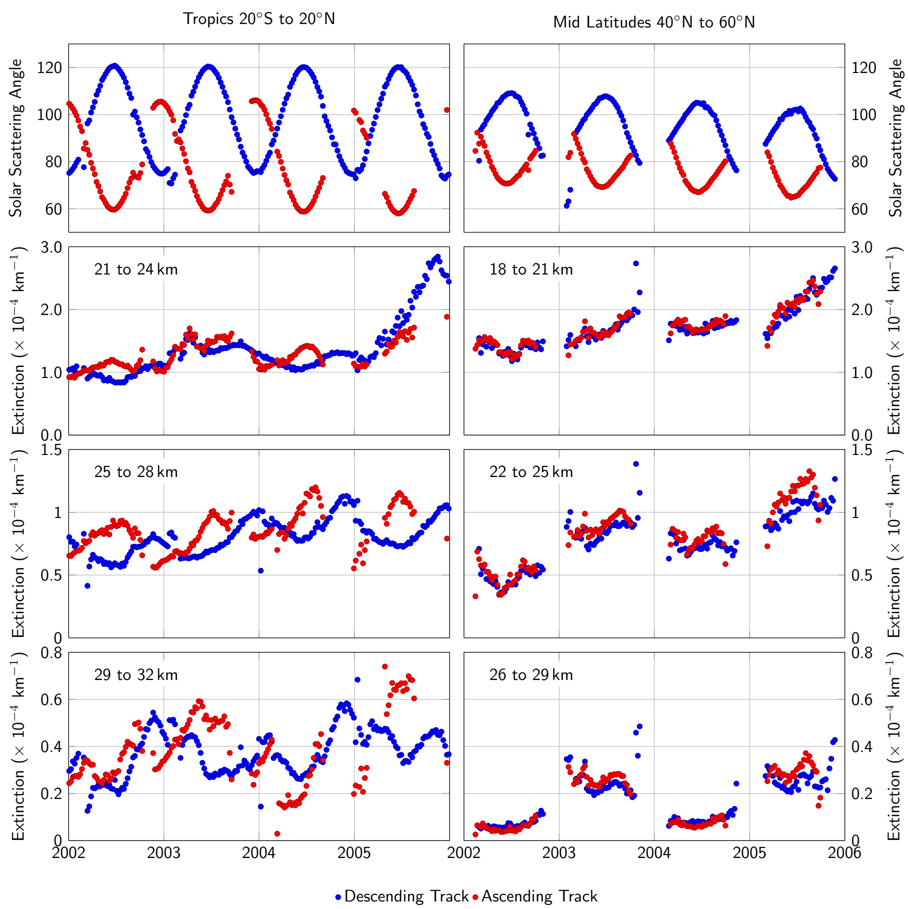

Figure 1: Comparison of the ascending and descending node OSIRIS version 5 extinction measurements for several altitude and latitude bands. The left column shows tropical measurements between 20N and 20S while the right column shows mid latitude measurements between 40 and 60N. The top row shows the solar scattering angle of the measurements. In the tropics measurements show a systematic difference depending on satellite track which correlates well to the solar scattering angle. In the mid latitudes much smaller differences are present.

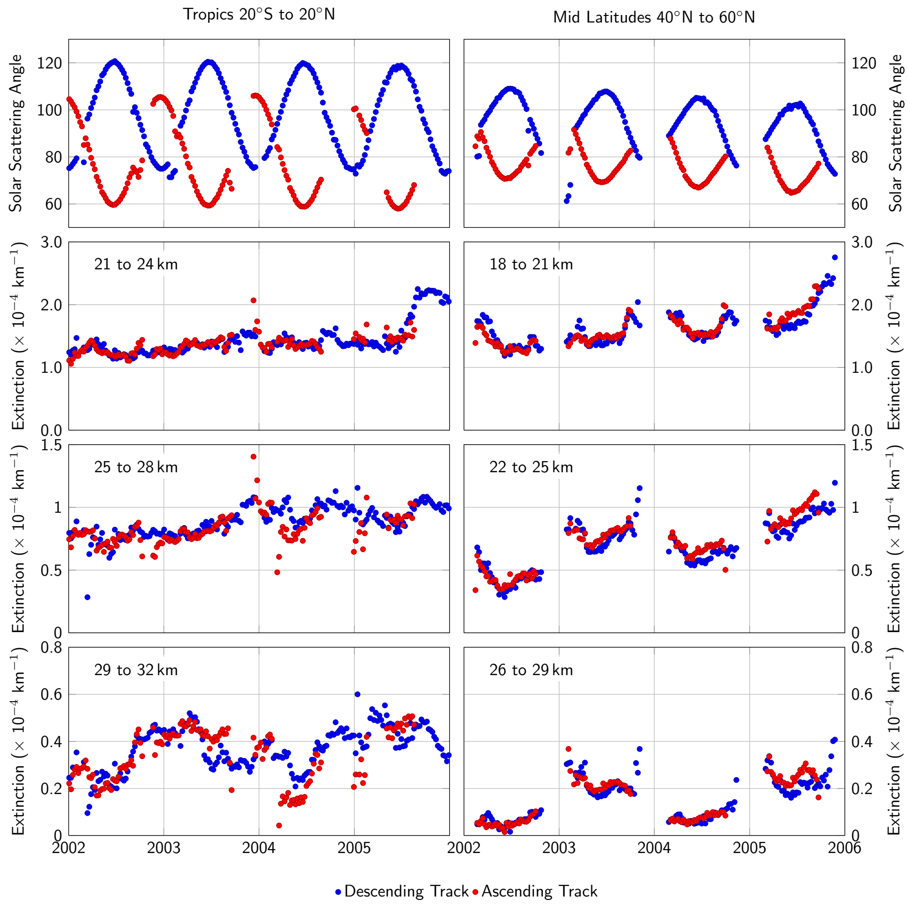

Figure 2: Same as FIgure 1, except using the version 6 data. Much smaller difference are now present between ascending and descending nodes in the tropics.

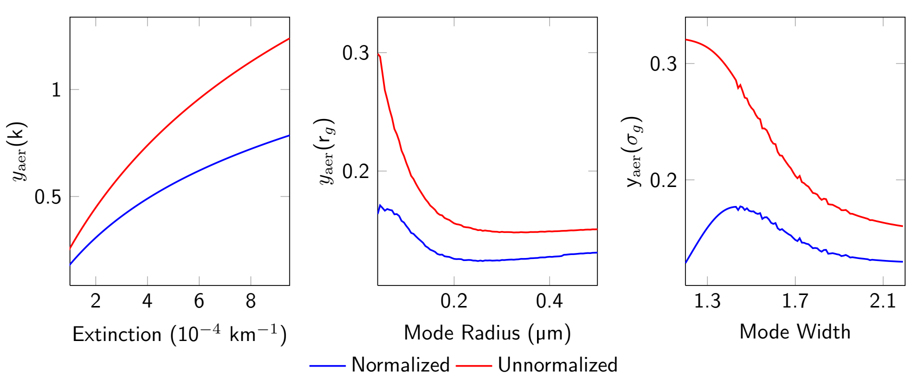

Figure 3: Simulated normalized and unnormalized measurement vectors as function of extinction, mode radius and mode width.

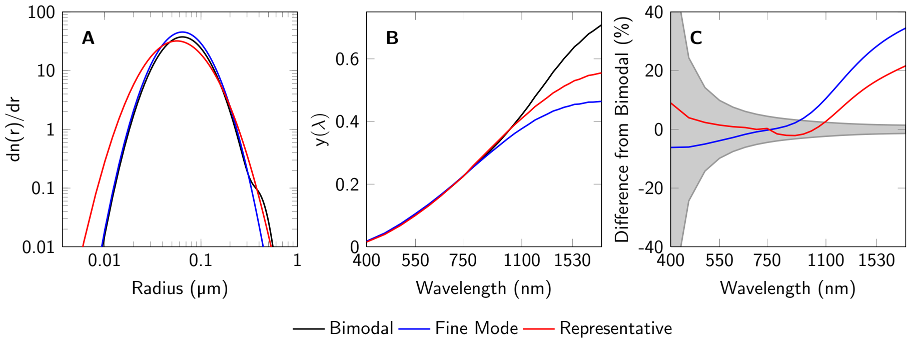

Figure 4: Panel A shows the 3 size distributions used in the simulations at 22.5 km, corresponding parameters are included in table 2. Panel B shows the measurement vectors as a function of wavelength for the three cases. Panel C shows the relative difference in the measurement vectors from the true bimodal case. The shaded grey area is the relative error in the bimodal measurement vector due to a 1% error in the measured radiance.

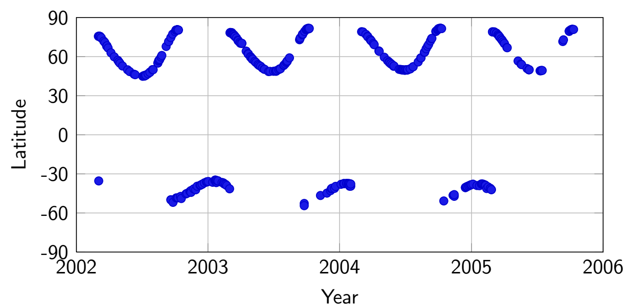

Figure 5: Latitude of the coincident SAGE III/OSIRIS scans as a function of time.

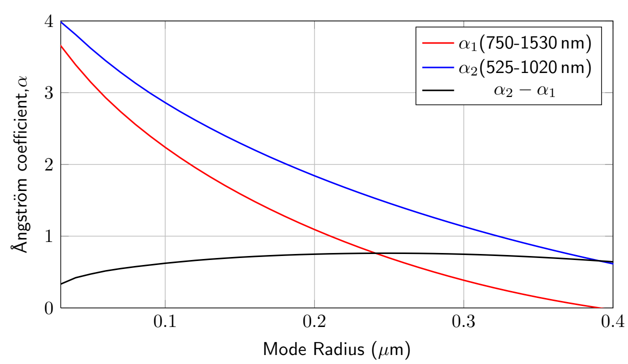

Figure 6: Angstrom coefficients as a function of mode radius for the SAGE II (red) and OSIRIS (blue) wavelength ranges given a lognormal distribution with a mode width of 1.6.

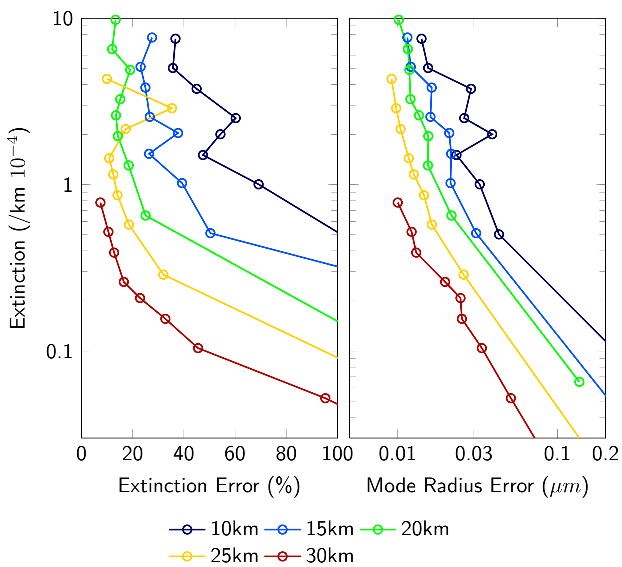

Figure 7: . Error in the retrieved extinction and mode radius parameters due to measurement noise as a function of extinction and tangent altitude. This was calculated by retrieving the error of a typical forward scatter geometry with varying amounts of aerosol loading.