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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Atmospheric effects of volcanic eruptions as seen by famous artists and depicted in their paintings" *by* C. S. Zerefos et al.

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The authors' idea to use paintings to reconstruct time series of volcanic eruptions is highly ingenious. It is probably one of the most interesting applications of libRadtran so far and I admire the amount of work put into this analysis, by collecting this huge number of paintings and retrieving ancillary information such as the solar zenith angle etc. For the analysis the authors calculated red/green (R/G) irradiance ratios and compared them to values derived from paintings. The model-calculated R/G ratios were systematically lower than the observed ones (Figure 3 of Zerefos et al (2007)) - in fact, the modelled ratio was almost always smaller than 1, indicating a blue or grey color rather than red. For that reason, the observed R/G values had to be reduced by 30% to be comparable with the model. On the other hand, the retrieval procedure (Figure

4) is highly sensitive to uncertainties of the model and the observations, for which the model needs to give as accurate values as possible. Here I give some suggestions how to get more realistic colors with libRadtran, to further improve the analysis of the authors.

1. The authors used the irradiance at 700nm for red and 550nm for green. This is probably a good proxy, but the correct way to calculate red and green values is to weight spectral irradiance with the CIE color matching functions to get the tristimulus values X, Y, and Z which can then be converted to color (R,G,B) values for a specific device. The method has been incorporated in libRadtran and is available since the last release 1.2 from December 24, 2006. With "output rgb" in the input file, colors are calculated instead of irradiance or radiances which can directly be used to calculate an image. For a more detailed description and a first application of the option please refer to Mayer and Emde (2007).

As it is not possible to include images in an ACPD comment, I prepared a webpage, showing some Figures and animations. For all following references to Figures please see *http://www.bmayer.de/diurnal/index.html*. Figure 1 shows sky radiance distributions, calculated with libRadtran for different aerosol conditions. The plots and animations show a full 360° panoramic view of the sky. For a pure Rayleigh atmosphere (top plot) the location of the sun is not visible at all. This is due to the fact that Rayleigh scattering is nearly isotropic for which reason a photon looses it's memory of it's original direction already after one scattering. Please note that the direct contribution of the sun (which would be a tiny, extremely bright spot) is not included in the picture but only the scattered radiance. The scattering phase function of aerosols, on the other hand, is peaked into the forward direction - in consequence the radiance distribution shows an aureole around the sun which intensifies with increasing volcanic aerosol, as does the red color close to the sun around sunset. A full 360° panoramic view, however, is rather uncommon for a painting, as it is for the human eye. For that reason, Figure 2 shows a smaller selection of the sky, centered around the sun, more typical for a painting. The selected angular range corresponds to a 35mm camera with a 28mm wide-angle lens. In this view the red color around sunset becomes more obvious. Please note that for all calculations we included also some tropospheric background aerosol (the libRadtran default aerosol: spring/summer, rural, visibility 50km, according to Shettle (1989)).

2. The authors derived R/G radiance ratios from the image, averaged over some angular range. On the other hand, with the model they calculated diffuse irradiance, that is the integral of the radiance, weighted by the cosine of the zenith angle, over the complete hemisphere. For a more quantitative comparison I suggest to calculate radiance close to the sun instead of irradiance. Figures 1 and 2 (at *http://www.bmayer.de/diurnal/index.html*) clearly show that in the model the overall color of the sky is still blue even close to sunset. In my calculations the R/G ratio for the irradiance was always smaller than 1, as in the calculation by the authors, in particular since the horizon is suppressed in the calculation of irradiance. If we, however, calculate the R/G ratio for radiance and average over some smaller angular range around the sun such as in Figure 2, the R/G ratio becomes larger than 1. I therefore suggest to base the retrieval on radiance rather than irradiance.

3. Zerefos et al (2007) calculated the R/G ratio as a function of optical thickness. I want to point out here that the documentation of libRadtran is a bit uncomplete concerning the way how the user-defined optical thickness of the aerosol is applied. The latter does not affect the stratospheric profile which is taken as provided by Shettle (1989) and not modified. Only the tropospheric part is changed which is what the majority of the libRadtran users requires. We decided to do that because specifying a large optical thickness by the user can result in highly unrealistic peaks in the stratosphere if the whole profile is scaled, while the user most probably intended to describe a situation with haze in the boundary layer. Figure 3 (at *http://www.bmayer.de/diurnal/index.html*) shows the four volcanic aerosol conditions as provided by Shettle (1989) and implemented in libRadtran (top plot). The bottom plot shows how the profiles are affected when an integrated optical thickness is specified by the user. As stated above, only

the lowermost 5km are affected and the stratosphere stays unchanged. Of course the stratospheric profiles can also be changed by libRadtran but that requires explicit definition of an extinction profile by the user. The documentation of the next release of libRadtran will be improved in that respect. I don't think that the effect on the results of Zerefos et al (2007) is too severe. In fact, when doing the calculations for Figure 3 we discovered a small bug in libRadtran which caused a distortion of the aerosol profiles if a too low optical thickness was specified. This will be fixed in the next libRadtran release.

4. For the calculation of radiances like for Figures 1 and 2 (at *http://www.bmayer.de/diurnal/index.html*) one has to consider that the sdisort solver included in libRadtran is only a pseudo-spherical but not a fully spherical code. That is, the direct beam of the sun is treated in spherical geometry while the scattered radiation is handled plane-parallel, as in the regular disort code. The pseudo-spherical solution is usually a good appoximation for irradiance as calculated by Zerefos et al. (2007). For radiance distributions, howver, especially close to the horizon, the uncertainty might become larger which can only be tested with a fully spherical model. We plan to do this with our new fully-spherical Monte Carlo code (Emde and Mayer, 2007) which, however, is beyond the scope of this comment because Monte Carlo calculations can be quite time-consuming if not carefully optimized for a specific problem. Zerefos et al. (2007) used the pseudo-spherical approximation for solar zenith angles as large as 100°. Although it obviously provided meaningful results in this case, I want to warn other users that sdisort can be become rather unstable for solar zenith angles larger than 90°.

5. Finally, I want to mention that the most beautiful and red sunsets occur during broken cloud conditions. If one googles for "sunset" at *http://images.google.com*, the majority of the images and in particular the really red ones include broken clouds. The reflection the scattered light at the lower boundary of the clouds obviously intensifies the R/G ratio. To include broken clouds in a radiative transfer calculcation around

or after sunset, however, is a highly challenging topic which would certainly justify a separate publication.

In summary, the approach to derive information about volcanic eruptions from paintings is highly innovative. There is a paper by Lynch and Futterman (1991) who derived information about particle sizes of an volcanic eruption from a black-and-white image. With this text I wanted to comment on the underestimation of the R/G ratio by libRadtran and make some suggestions to further improve the analysis.

Finally we suggest to use the more recent "standard publication" by Mayer and Kylling (2005) to reference libRadtran instead of the 1997 paper.

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