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Title: 30-year lidar observations of the stratospheric aerosol layer state over Tomsk (Western Siberia, Russia)

We thank Referee 1 for valuable comments, questions and suggestions which will allow us to improve our manuscript.

Point-by-point response to Referee 1

2 Lidar instruments and methods

Comment: I would like to see a short description of the lidar photon-counting data acquisition electronics. Is it from a commercial vendor or built just for the lidar?

Our response: The SLS aerosol channel data acquisition electronics we used is of in-house design and manufacture. A more detailed technical description of the SLS aerosol channel and its data acquisition electronics can be found, e.g., in (Burlakov et al., 2010). We will include the reference in the final version of our manuscript.

Burlakov, V. D., Dolgii, S. I., and Nevzorov, A. V.: A three-frequency Lidar for sensing microstructure characteristics of stratospheric aerosols, Instrum. Exp. Tech., 53, 890–894, doi:10.1134/S0020441210060230, 2010.

We added the following sentence to the revised manuscript:

"A more detailed technical description of the SLS aerosol channel and its data acquisition electronics can be found, e.g., in (Burlakov et al., 2010)."
[**Page 4, lines 10 and 11, revised manuscript**]

Comment: Is signal induced noise, and counting saturation taken into account?

Response: Yes. We take into account both photomultiplier tube (PMT) afterpulses and photon-counting saturation. Furthermore, current pulses from a PMT are fed to a broadband amplifier and a differential amplitude discriminator. The latter allows controlling the lower and upper discrimination thresholds of dark-current pulses of a particular PMT specimen under the conditions of real background illumination, i.e., selection of the optimal discrimination thresholds for increasing the signal-to-noise ratio (see, please, Sect. "Technical description of the lidar" in the mentioned paper Burlakov et al., 2010).

Comment: I would like to see more about the normalization. Is only a single altitude used? Is it 30 km? Many of the Scattering Ratio profiles shown in the paper haven't decreased to 1.0 at 30 km, so higher altitude data must have been used. Is there an objective way to do this?

Response: The SLS aerosol channel makes it possible to receive almost undisturbed backscattered signals from altitudes of ~ 40–45 km. At higher altitudes, the signal-to-noise ratio is too low. Therefore, altitudes of ~30–35 km, where the stratosphere is considered to be aerosol-free, were used as the calibration altitudes.

Comment: Choosing H1 (lower attitude of the SAL) as 15 km seems reasonable, but other lidar groups have used the actual tropopause or tropopause + 1 km. Choosing this altitude can be complicated since there can be multiple tropopauses sometimes. It can also be complicated when there has been an eruption since the upper troposphere can have much more aerosol. But perhaps you can comment on how much of a difference it would make to lower the H1 altitude during background conditions.

Response: Tomsk is located near the southern boundary of subarctic latitudes, where the tropopause altitude can vary significantly (from ~11 to 13 km, depending on season), e.g., due to migration of the Arctic stratospheric jet stream within our (Tomsk) region. Sometimes one can observe a double (or even multiple) tropopause. Therefore, we consciously removed the interval of the tropopause altitude variations to observe the stratospheric perturbations only. Probably, some information about the lowermost stratospheric aerosol perturbations could be missed.

Instead of
"In our case, the tropopause altitude over Tomsk varies from ~11 to 13 km, depending on season, and therefore, we set H_1 = 15 km."

we wrote

"Tomsk is located near the southern boundary of subarctic latitudes, where the tropopause altitude can significantly vary, e.g., due to migration of the Arctic stratospheric jet stream within the Tomsk region. Sometimes one can observe a double (or even multiple) tropopause. For this reason, we consciously removed the interval of the tropopause altitude variations to observe the stratospheric perturbations only. As the tropopause altitude over Tomsk varies from ~11 to 13 km, depending on season, we set H_1 = 15 km."

[**Page 4, lines 23–26, revised manuscript**]

3 Results of the SAL lidar observations over Tomsk

3.1 Time series of the integrated stratospheric backscatter coefficient (1986–2015)

Comment: In Table 1 the maximum plume height is listed. How are these measured? The initial plume heights are not very accurate if done by naked-eye observations. Are these measured later with lidars?

Response: The maximum plume altitudes (MPAs) presented in Table 1 were taken from the Smithsonian Institution Global Volcanism Program. The Smithsonian MPA values were determined from the pooled analysis of visual and radar observations. When it was possible, the MPAs could also be determined with space-borne lidars more accurately compared to the mentioned observation methods. Considering in Sect. 3.5 the 2014 Kelut eruption as an example, we discussed the difference between MPA values determined via the space-borne lidar CALIOP and visual/radar observations.

Comment: There has been an ongoing discussion in the community about whether there is an annual cycle in SAL. Your Figure 2 shows a winter/summer ratio of about 1.35. Figure 3 is similar. This would be influenced by the choice of the H1 altitude. It would be interesting to calculate a ratio and error bar as your best estimate of an annual cycle. In Figure 2 what do the error bars represent, one sigma of the spread of the data?

Response: First of all, Figure 2 is now Figure 3 and, conversely, Figure 3 is now Figure 2 in the revised manuscript. We have extended the analyzed period of the background aerosol loading variations over Tomsk up to 16 years (1999–2015), instead of the period 2000–2006 in the old version of our manuscript. The monthly average B_π^a data for March–June 2000 (after the Hekla eruption), August–November 2008 (after the Okmok and Kasatochi eruptions), August–October 2009 (after the Sarychev Peak eruption), and also April and August–October 2011 (after the Merapi, Grimsvötn, and Nabro eruptions) were not taken into account. The exclusion of these perturbed data allowed us to extend the analyzed period of the background aerosol loading variations and, therefore, to improve the statistical reliability of the B_π^a data series. The B_π^a values were averaged separately for the westerly and easterly phases of the quasi-biennial oscillations (QBO) characterized by zonal winds in the equatorial region at 30 mbar (Fig. 3, ex-Fig. 2). Based on these 16-year averaged values of the monthly average B_π^a, we show that an annual cycle in SAL exists. Moreover, based on the inter-annual B_π^a variations (Fig. 2, ex-Fig. 3) separately averaged over the warm (April to September) and cold (October to March) half-years, we also show that aerosol loading of the mid-latitude stratosphere is maximal in the cold half-year, when the meridional air mass transport dominates (especially during the westerly phase of the QBO), and it is minimal in the warm half-year, when the zonal transport dominates. All error bars in Figs. 2 and 3 represent the standard (1–σ) deviation. As a whole, we considerably rewrote Sect 3.1. See, please, the colored version of our revised manuscript for details.

3.2.1 Okmok and Kasatochi

Comment: In Figure 5 there is a peak on September 4, 2000 at 27-30 km. Is that real?

Response: Yes, you are right. There are two small peaks of the scattering ratio profile (4 September 2000) at altitudes of 27 to 30 km in Figure 5. However, we believe that these peaks are not related to any aerosol events in the stratosphere and, therefore, they represent measurement uncertainties due to the low signal-to-noise ratio.

Comment: The altitude axis might be clearer with 1 km tic marks instead of 1.5 km.

Response: We agree. Done.

4 Discussion and conclusion

Comment: "The Happy Camp Complex fire consumed more than 134 acres (~543 km2)...". Acres are much smaller than km2, something is wrong with the areas.

Response: Thank you. We corrected the mistake: 134 acres ≈ 0.543 km^2. However, we removed the information about the Happy Camp fire from the text of our manuscript.

Comment: Figures 6 (a), 6 (b), 9, and 11. I am amazed that all four trajectories almost exactly cross over the volcanoes after so many days. Did you find an optimum altitude or something that gave you the best trajectory? Were the trajectories sensitive to the initial conditions?

Response: We usually calculate a set of the HYSPLIT backward trajectories which start from different aerosol layers detected in the stratosphere over Tomsk after a volcano eruption (See, please, Fig. 11 in our revised manuscript). A signal integration period of 20–30 min yields uncertainties in the start time and altitude (i.e. in initial conditions) of a backward trajectory. Therefore, we usually present the best trajectory to illustrate a possible way of how aerosol from an erupted volcanic plume could pass and be detected over Tomsk.

Sincerely,

Authors