

## ***Interactive comment on “35 years of stratospheric aerosol measurements at Garmisch-Partenkirchen: from Fuego to Eyjafjallajökull, and beyond” by T. Trickl et al.***

**Anonymous Referee #2**

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The Garmisch stratospheric aerosol record is the longest record available in the European sector, and this record has made a number of important contributions to our understanding of the dynamics and measurement of stratospheric aerosol. This manuscript extends that record up to the present and also presents a smorgasbord of additional miscellaneous phenomenon measured at Garmisch, polar stratospheric clouds, the stratospheric impacts of Pyro CBs, and most recently signatures of the Icelandic volcanic eruption, Eyjafjallajökull, in 2010.

The problem with this approach is that these various phenomenon are not all that related, except that they can all be measured with a lidar. Thus the paper lacks a

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strong scientific focus. The paper and the measurement record would be well served if the authors focused on one major topic. I suggest the long term stratospheric aerosol record, and then showed how the recent volcanic record is captured, or missed, by the Garmisch measurements, how somewhat random events such as polar stratospheric clouds, pyro CBs, tropospheric volcanoes, appear in the record, and finally to spend more time to explain the factor of 5 or more increase in integrated backscatter between 2008 and 2009, which has then remained at levels similar to the levels observed three years post Pinatubo or El Chichon, but with much larger variability. This change is much larger than the 3-5% per year increase suggested by the Mauna Loa record. The authors focus as much space on 2004-2006 at Garmisch, when that change was rather minor, as they do on the much larger and more recent changes. The authors are also on a bit of a mission to refute the claims that coal burning in China may be impacting stratospheric aerosol, and to support the alternate claim that the changes are due to low level volcanism; however, their arguments along these lines are not based on the Garmisch measurements, but on other measurement records, which have already been discussed along these lines (Vernier et al., 2011). Thus the paper gets distracted from the strength of the Garmisch measurements.

I would very much like to see this stratospheric aerosol record presented and discussed for what it contributes to our knowledge of recent changes in stratospheric aerosol, what it contributes to the long term evolution of stratospheric aerosol, and how random events, polar stratospheric clouds, Pyro CBs, tropospheric volcanoes, do not really impact the record, while a series of low level volcanic eruptions, do impact the record. The authors are not very discerning about which volcanoes are included in their list at the bottom of Fig. 1 and Table 1. They should focus on only those volcanoes with clear stratospheric signatures at Garmisch, while at most mentioning those without clear signatures or with tropospheric signatures at Garmisch.

If, however, the authors choose to maintain the current approach of a rambling discussion of a smorgasbord of Garmisch measurements, and a discussion of recent

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controversies in stratospheric aerosol, and their opinion of these controversies, based on measurements by others, then I am not sympathetic to publication. In the latter case the paper should be recast into a focused discussion solely related to this latter point about recent volcanism. Then the paper can be judged based on the merits of that argument, while being aware that these points have already been addressed by others more responsible for these other measurements. In what follows I offer specific comments made while reading the paper. Some of it is editorial, while the rest is supporting the points above. I do this in the order of the written manuscript. Since no line numbers were provided, I indicate position with page number.paragraph number, and let the authors find the text in the paragraph based on the comment. Partial paragraphs at the top and bottom of a page are counted for that page.

Abstract: Stick to what is new in this paper and its contribution to the science. Save for the discussion subjects such as the reason for the increases in stratospheric aerosol recently observed and the record of recent volcanic eruptions. Focus on the Garmisch measurements.

3.1. Revise as follows, With the advent of laser sounding (Fiocco and Grams, 1964) and regular balloon borne (Hofmann et al., 1975) and satellite (ref for SAGE II) observations, a time series could be obtained. For recent reviews see (Deshler et al., 2006; Deshler, 2008). The measurements have covered a number of important eruptions and have led to a clear . . .

3.1. Some mention should be made of the sulphur gases which are transported to the stratosphere and maintain the non-volcanic fraction of stratospheric aerosol.

3.2. What does the word powerful add, here, and elsewhere? Such strong adjectives generally do not help the scientific content of the statement, but rather confuse it.

4.1 "rather remote"? Does this mean unpopulated?

Pg 4. Given the focus of the paper, described in the last paragraph on this page, on a

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fairly long period of low level volcanic activity with stratospheric impacts, the extensive material and references on the eruption of Eyjafjallajökull, a tropospheric eruption, are misplaced.

Section 2/Figure 1. Some mention should be made of the reason for the data gap, 2002-2004.

8.2. Delete 'in the preceding publication'.

9.2 Delete, 'Some of these events are discussed in the following section.'

9.4. This paragraph is rather speculative. There are no Garmisch data mid 2002-2004 and the last points in 2002 were quite low. A fairer statement would be that the measurements during 2000/2001 were higher than those during 2004, thus the increase observed after 2004 was not apparent in the 2000-2002 data.

9.5 What two latitude ranges? Why are they extensive? Underestimated by whom? Why are the number of eruption periods impressive? It is also not so obvious the importance of the eruptions between 5 and 10 km. Do these influence stratospheric aerosol? Perhaps through increasing the atmospheric sulphur burden, but probably not directly, and their sulphur contribution would have to be compared to the global flux of sulphur to see if it is significant. The more important eruptions are the ones above 10 km, and there were a few days in mid 2005 for this case. But the goal of this figure is not clear. Recall the increase at Mauna Loa began in 2000, so if this figure is to provide information about that record it should extend back to 2000. Overall the extensive focus here on this short Garmisch record with minimal changes is misplaced. The later, larger changes are of more interest.

Table 1. It would be nice to include latitude and volcanic explosivity index.

10.2. Where is it obvious that the number of mid-latitude eruptions were few prior to 2005, and then increase, Table 1, Figure 1, Figure 3? According to Figure 3 the number of high latitude periods with  $h > 10$  km has remained flat. Next sentence, what is the

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early phase? Again the authors have not shown the data back to 2000 and are basing these statements on perhaps 5 high latitude eruptions which probably did not influence Mauna Loa's latitude much, if at all. The next statements regarding the tropical eruption are not supported by tables or figures, and are a bit rambling.

In fact this whole section is off the main topic of this paper, which is the Garmisch measurements. It would be much more interesting if the authors could identify those volcanoes which may have influenced the Garmisch measurements, and could document/explain the changes observed in that record, rather than a broad discussion of all the volcanism in the last 10-15 years, and then challenging the conclusions of Hofmann et al. (2009). Those conclusions have already been challenged along these same lines by others, e.g. Vernier et al. (2011).

Section 3.3. This section reviews several papers by Fromm et al., in which the Garmisch measurements played a role. Thus all of the detail provided here is not necessary. It has been published. Nor is Fig. 4. The suggestion that fires may become more abundant in the future and an investigation of the past record on this point is, of course, interesting, but again is not what this paper is about, or should be about. The authors should stay focused on presenting their measurements. I would recommend just a short description of the fires locations and the aerosol plumes tracking to Garmisch, then pointing out in Fig. 1 when these events were observed. From Fig. 1 the two main points of the authors, that even large fires contribute little to the overall stratospheric burden, and that their time frame of influence is quite limited, will be immediately obvious.

Section 3.4. This event while interesting, contributes nothing to the overall stratospheric burden and is even more limited in time. Two events in 40 years? I don't see the value for this paper of section 3.4 and Fig. 5 & 6.

Section 3.5 A better title would be - Increase of volcanic activity 2006 – 2012. That way it is consistent with sections 3.1 and 3.2. It could be more interesting to point out

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the presence of polar stratospheric clouds as they appear in the long term lidar aerosol record.

12.2. We do not need all this detail? A simple statement that minimum temperatures were  $-70^{\circ}\text{C}$  will convince the reader that a PSC was not observed.

12.4. Change to. We now believe that a layer from the Soufriere ...

13.1. What is the final round? ... wide vertical distribution ... here and elsewhere? What kind of distributions (altitude, size, ???)? The authors intent should be specified.

13.2 Join with previous paragraph and begin. "The only other possibility is the eruption ... 18 km; however, this eruption was short ... south." Last sentence is unnecessary.

13.3. This paragraph doesn't seem to be related to the Garmisch measurements and should be dropped. Some of the references could be used to qualify the statement, "Because of the strong eruptions occurring in spring 2009. ..."

13.4. I don't understand this sentence, "The scattering ratios (not shown) outside narrow structures, converted to 532 nm, grew from 1.1 to 1.4 during that period in agreement with the results of the NDACC lidar before and after the gap." The scattering ratios from the NDACC lidar are not shown either, to my knowledge. What is the intent? Perhaps the integrated backscatter could be shown to be in agreement with the NDACC lidar before and after using Figure 1.

13.5 – end of this section. I do not understand the point of showing two examples for how the DIAL system could be used. One is sufficient. The discussion primarily just consists of a description of the figures with some numbers added, but doesn't add anything beyond the figures until we get to the last paragraph of section 3.5. I recommend removing Fig. 8 and the discussion of Redoubt. Use Fig. 9 as the example of the utility of the DIAL system, but skip the figure detail and focus on the last paragraph.

Section 4. After roughly 2.5 pages and 3 figures for the period 2008-2011, the most interesting period in the recent Garmisch record, the paper spends 6 pages and 8, out

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of 19, figures on Eyjafjallajökull, a clearly tropospheric eruption, which was observed for just one month at Garmisch. This emphasis is misplaced, and this section should be shortened considerably. Never the less, I read this section and have the following comments.

16.4 – Why is Fig. 10 introduced after Figs. 11-14? I am not convinced that presentation of all these trajectory calculations are necessary.

17.2. Where is the 14.3 km layer observed? It is not apparent on any of the Figs. 11-13. This emphasizes the last statement in this paragraph, because so far nothing here leads me to believe in a stratospheric impact.

17.3. What am I missing? According to Table 2 Keflavik and Munich have quite similar humidities. The numbers for the first 5 days are: Keflavik (47 60 40 38 76 69 79 37 23 33 57 85) and Munich (52 36 93 69 89 57 81 30 36 40 32 63).

These numbers do not imply that Keflavik was significantly more moist. In fact one could argue the opposite, but generally they are quite similar overall. What range of humidity is favorable for aerosol growth. Which really isn't aerosol growth as much as aerosol deliquescence, moisture the aerosol will lose when it reaches the next dry area, so the point of this discussion is confusing. For similar reasons I am not sure the point of showing Fig. 14 which is not in RH, but in H<sub>2</sub>O number density and just serves to show that the air over Garmisch was dry on April 19 as already evidenced from Table 2.

17.3. Arguing that the narrow layers in Fig. 13 near the tropopause are cirrus is not hard even if the DIAL water vapor measurements do not show a humid layer. Notice the significant difference between these layers and the previous volcanic layers shown in Figs. 11 and 12 which have widths of 0.5 km or more. Here the layers are a few hundred meters at most. In addition the backscatter coefficient is different by an order of magnitude according to the axes labels, which is confusing. According to the axes labels the majority of measurements in Fig. 13 would appear below the  $0.01 \times 10^{-6}$

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sr-1 m-1 line in Fig. 12. Yet they are both 532 nm measurements. The harder question is whether the cloud formed on a volcanic aerosol layer and that is not well shown here.

22.3. This paragraph is not derived from this paper, but is again a discussion of a major sub text of this paper, ascribing any recent changes in stratospheric aerosol solely to volcanism, which has been the subject of other work. In this regard the last sentence is unusual. What is it based on? The tropical tropopause is in the 16-18 km range, yet no tropical volcanoes listed in Table 1 come anywhere close to this level. The only ones which penetrate 15 km are all high latitude volcanoes.

Fig 18 is a nice picture, but is not appropriate here. Particularly considering the very next sentence.

How is the quasi-horizontal leaking and Figure 19 related to the results presented so far? This is the first introduction of this new point just one paragraph before the end of the paper.

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