Answers to the interactive comments by anonymous Referee #3 on "On the absolute calibration of SO_2 cameras" by P. Lübcke et al.

The comments of the Referee are printed in usual black font and our answers are printed in bold font. Text that was changed or added to the revised manuscript is printed in italic.

Anonymous Referee #3
Received and published: 31 December 2012

This paper presents a valuable contribution to ensuring that an accurate calibration for the high temporally and spatially resolved SO2 cameras is performed. It provides a thorough characterization of the detector sensitivity and inter-comparison between various techniques currently used in monitoring SO2 from volcanic plume sources. The paper is well structured and written and I recommend publication after some mostly minor changes.

We would like to thank the author for his constructive and very helpful review. Our answers to the comments are below:

Major comments

Page 6185
Line 3: light dilution requires definition as many readers will be rather unfamiliar with what this is referring to
- The referee is right here, a short definition will help readers unfamiliar with radiative transfer effects. However, we believe, that this should not be done in the abstract, but rather in the introduction.
We added a definition of the radiation dilution effect on Page 6186, Line 27:
"*e.g. multiple scattering inside the volcanic plume or the light dilution effect, i.e. radiation scattered into the light path between the volcanic plume and instrument without penetrating the volcanic plume, see Kern et al. (2010a)"*
The definition of the radiation dilution effect on Page 6194, Line 20 was removed.

Page 6186
Line 11 time resolution of 1Hz – and elsewhere often time resolution is actually given as a frequency and vice versus, these are different quantities, do not use interchangeably.
- The authors thank the referee for mentioning this inaccuracy. On this page the time resolution was removed (See Referee #2 Comments). The rest of the manuscript was checked for the correct use of time resolution and frequency.

Page 6187
Line 10: the discussion of aerosol's wavelength dependence is also true for the strong ozone absorption which occurs in this wavelength region and should be introduced here.
- The strong ozone absorption, which occurs in this region, is not much a problem for the SO_2 camera technique, since the larger part of absorption (>90%) occurs in the stratosphere and thus affects measurement and reference images alike. There is not much variation in the radiation intensity due to ozone absorption since the pathlengths in the lower troposphere of the radiation seen by the camera are largely the same. However,

ozone absorption might change the camera calibration with changing SZA, this is mentioned on P6194.

Page 6190 line 18 why is the range of 305 – 320 used for the band centred on 315nm with a FWHM of 10nm? Related the acronym CW is not necessary remove and write in full.

- The range 305 – 320 nm was used to describe the SO_2 camera technique in general, while we used the 315 nm with a FWHM of 10 nm as the filter set-up during our measurements. However, since Bluth et al. used a filter with a central wavelength of 307 nm and a FWHM of 12 nm, the range of 300 – 320 nm is more accurate. The range was changed to 300 – 320 nm through the complete manuscript.

Page 6191 line 25 – is the push broom method providing a truly independent second spatial dimension, as the description leads the reader to believe? Or rather is a higher sensitivity to the second spatial dimension, but is not independent of the first spatial dimension, and a complex retrieval algorithm is required to obtain the vertical and horizontal dimensions? If the latter, then here is a good place to describe the necessity of performing a complex radiative transfer retrieval to obtain the two spatial dimensions.

- The authors do not completely understand the question. We would like to certify, that the IDOAS does actually measures light arriving from two independent dimensions (e.g. Bobrowski et al. 2006). No complex radiative transfer retrievals were used, since all effects that influence the light path, influence both instruments in a similar manner.

We added a sentence to the manuscript to clarify this: '*Note that the IDOAS instrument determines the two-dimensional distribution of the SO_2 CD -- just as the SO_2 camera -- however, using the DOAS technique rather than Eq.3.***'**

Page 6196 the peak transmission information is repeated in this section, it is more informative on page 6197 line 8. Please be consistent with the use of peak versus central wavelength etc – central is more accurate.

- We removed the repetitive information in Line 3-4 on this page. The term peak transmission was used on purpose here instead of central wavelength. Since the wavelength of peak transmission λ_{max} is not necessarily λ_{CW} this should indicate, that even if we look at the wavelength with maximum transmission there is some radiation reflected at this wavelength.

No change to the manuscript was made.

Page 6198

Line 7: Are mass mixing ratios the preferred units (over volume mixing ratios)? Either way how is the temperatures within the plume dealt with – where do the temperature and pressure profiles to convert the number densities to mixing ratios come from?

- The authors like to thank the Referee for this very valuable comment. The authors prefer to give the column density in molecules/cm^2. ppmm are historically used in volcanic SO_2 measurements and are today the most commonly used units in the SO_2 camera literature (mostly without further definition).

We added a Footnote "[2]*We use the unit of ppmm similar to Kern et al. (2010a). The units molecules/cm^2 where converted to ppmm assuming standard pressure and a temperature of 20°C throughout the text: 1 ppmm=2.5x10^{15} molecules/cm^2."*

In an attempt to make the paper better accessible for readers which are more familiar with the unit ppmm, ppmm values were added in parenthesis throughout the manuscript. Figures F03, F07, F08, F09, F10, F11, F12, F13, F14, F15 were updated, and a second y-axis (with ppmm) was added.

Page 6204

Line 6 point the reader to the calibration curve later (rather bring the calibration figure forward as it is relevant here).

- Line 7: (e.g. Figure 7) was added to point the reader to one of the calibration curves.

Page 6204

Line 12: When was the change discovered, i.e. back in the laboratory after the measurement campaign was complete – i.e. the return transport could have also played a role? Or in the field at the end of the measurement campaign?

- The change was discovered back in the laboratory after the campaign was completed. We therefore cannot determine when the FOV of the DOAS telescope actually moved (most likely during the transport in the plane). The referee is right, it is not clear whether it changed on the way to the field or during the return trip. We therefore added on Line 13: '*transport to the measurement site or back to the laboratory'*

Page 6205 line 12 translate, rotate shear and scale ? The mathematically robustness is questionable with manually identifying features then applying a matrix, why are the features not able to readily found through correlations between the datasets and thus aligned?

- **The authors assume, that the Referee refers to the question, how accurately the parameters of the transformation were chosen, rather then, whether the mathematical operation itself is robust. We added an estimate for the uncertainty of the parameters to the manuscript (See anonymous Referee #2 Comments).**

Features were not found through correlation between the datasets, since the geometric transformation has to be known before the different images can be averaged.

With the IDOAS sampling outside the FOV of the camera, a true alignment is compromised, and in fact the instruments are simply sampling the plume differently (though with much overlap).

- The authors do not understand, how the alignment should be compromised, by the larger FOV of the IDOAS instrument. The referee is absolutely correct that the two instruments sample the volcanic plume with much overlap, but with two different methods (two-channel SO_2 camera retrieval vs. DOAS).

Relative to the comprehensive treatment of the DOAS comparison the IDOAS comparison is weak, the paper would benefit from a more robust comparison here.

- We added an error estimate for the comparison (see anonymous Referee #2 Comments), and moved the complete description of how the images were aligned (Sections 5.4) to the Appendix.

Page 6211

Line 24: radiation dilution effect – light dilution early, be consistent – and use a term more descriptive or well known in the literature such as scattering of radiation into the FOV due to the plume or something better.

- We changed radiation dilution to light dilution through the complete manuscript.

Minor comments

Page 6184 line 27 extend should be extent

- Changed “extend” to “extent”

Page 6193 line 23 insert this – but this increases. . .

- Changed “but increases” to “but this increases”

Page 6194, line 10 insert for: corrected for by. . .

- Changed “corrected by” to “corrected for by”.

A more detailed description of “geometric considerations” was added “geometric considerations (i.e, calculating the length of the light path through the cell for different illumination angles)”

Page 6194, line 22 move definition of light dilution to earlier in the text.

- The definition was moved to P6185, Line 3.

Page 6195 line 17 replace behind with with

- Replaced “*behind*” with “*with*”

Page 6198 line 15 here and 6201 line 3 less than (not then)

- Changed “*less then*” to “*less than*” in both instances.