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Atmospheric Chemistry and Physics Discussions

Interactive comment on "SO_2 and BrO observation in the plume of the Eyjafjallajökull volcano 2010: CARIBIC and GOME-2 retrievals" *by* K.-P. Heue et al.

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Interactive comments on "SO_2 and BrO observation in the plume of the Eyjafjallajökull volcano 2010: CARIBIC and GOME-2 retrievals" by K.-P. Heue et al.

We thank both referees for the helpful comments and suggestions, both referees suggested to shorten the paper, therefore we deleted 4 figures and 2 were modified. Also the DOAS sections were shortened. On the other hand a small discussion of the BrO to SO_2 ratio (1 new figure) is now included, and some details are clarified.
The specific answers to the comments are written below the comments in italics. Sometimes two comments are answered simultaneously.

Anonymous Referee #2
Received and published: 7 January 2011

The paper reports on aircraft and satellite measurements of SO_2 and BrO in a part of the Eyjafjallajokull plume when it was over the UK and Ireland on 16 May 2010. The paper compares aircraft and satellite DOAS data, which is quite difficult because of the different foot print sizes and therefore different air masses involved. The aircraft data on the composition of the plume are very valuable and deserve a good discussion. But the paper addresses many different topics, and is a bit chaotic. Furthermore, the paper is quite long and has many figures. If possible, please reduce the size of the paper and/or number of figures.

Main comments:

(The pages are only indicated with the last 2 digits and the line numbers are those on the relevant pages of the screen version of the paper.)

(1) The error in the AMF for the CARIBIC DOAS measurements is stated to be smaller than 7% (p. 38, l. 14); this value is surprisingly small. Is it only the noise or also the bias in the AMF modelling? What is the effect of errors in the input of the AMF calculations, e.g. the effect of clouds or vertical trace gas profile on the AMF error?

See also our answer to the comment by referee #1 on the same topic, the 7% is only the statistical error. We did not perform a detailed sensitivity study on the plume altitude as we are confident in our measurements and believe the plume really was between 3 and 6 km altitude. But we checked on slight variation in the altitude ($\pm$ 500m) and found no significant differences. Nevertheless the errors can be quite large and therefore in section 3.2 all the efforts are described to get the best information available for the AMF calculation.

(2) The footprints of GOME-2 and the CARIBIC DOAS instruments are very different; please specify the difference. Therefore, the effects of clouds on the AMF will be very

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different. In Sect. 2.3, p. 43 it is stated that the same cloud and aerosol settings are used for GOME-2 and CARIBIC DOAS radiative transfer simulations. This seems unrealistic. Please explain.

The footprint of CARIBIC is a small line that is 200 m wide and 2km long for 7 km altitude. A GOME-2 pixel is 40 x 80 km. The GOME-Pixel size is mentioned in the respective section, the width of the CARIBIC footprint can be calculated easily as the opening angle of the telescopes is now given.
The effects of clouds are different for GOME-2 and CARIBIC, but for the simulations the same cloud properties (cloud top altitude = 1500m, cloud optical thickness = 10, cloud albedo = 0.999) are used. These settings are independent from the viewing geometry of the instrument. Of course the assumption that the cloud and aerosol properties will be constant within the GOME-2 pixel is critical, but from my point of view these are the most realistic settings for the plume and the near surrounding.

(3) A quantitative comparison between GOME-2 and OMI SO_2 data is missing. Only figures are shown. Since the same type of satellite remote sensing data is involved, a quantitative comparison is well possible. The few hours time difference should not be an obstacle. An option is to integrate the SO_2 over the plume for both satellite instruments, and then compare SO_2 columns.

There are at least 4 satellites (SCIAMACHY and GOME besides OMI and GOME-2) that might have observed the plume or at least parts of it. A comparative study between the individual satellite instruments might also be very interesting but will be a different study.
As there is only a small overlap with CARIBIC DOAS no correlation plot between GOME-2 and CARIBIC is shown. The difference of few hours has a large influence on the comparison (e.g. Heue et al., 2010), therefore no comparison to OMI is given.

Smaller and textual comments:

Abstract:

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- please give quantitative results of the SO_2 and BrO columns or concentrations measured in the plume.

Done.

- p. 33, l. 14-15: please give the conclusion from your work: was the measured SO_2 indicative for ash in the plume? Or can't you say anything about this because the particle counter failed?

The optical particle counter would have added very useful information concerning the plume, if it were available. However, the O_4 data indicate that the horizontal position of the ash plume and the SO_2 were the same. No information about differences in the altitude range could be retrieved.
The colocation of the O_4 and SO_2 observations is added to the abstract.

Introduction:
- p. 33, l. 21-22: also the meteorological conditions, esp. wind, strongly influence the affected region

Yes, the Eyjafjallajökull was a perfect example.
It is included in the text.

- Eqs. R1-R6 should be introduced with a preceding sentence.

Done.

Sect. 2.2:
- Eq. 1: typo: the exponent (SCD x sigma) should be negative

Corrected.

- Acronyms like SCD and VCD should not be used as symbols in formulae. This holds for most equations in the paper.

I don't agree with the referee in this point. When writing a whole page of equations by

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hand, we are used to omit the dots for the multiplication and therefore a variable must not have two or more symbols for clarity reasons.
But when writing a text (paper) with the computer we may easily include a "·" in the equation and for the readability of a few (5) equations in a longer context it is from my point of view better to use acronyms.
"For the conversion of measured SCD to VCD an Air Mass Factor (AMF) is introduced as the ratio between SCD and VCD:

A=S/V

where V is the VCD, S the SCD and A the AMF "
Here a one letter variable is introduced to shorten a three letter acronym, in my opinion this just causes confusion.

- p. 37, l. 20: "Because of that ...": sentence is unclear, please reformulate.

Clarified: "By including a reference spectrum the absorption of the reference relative to the solar radiation is subtracted in the retrieval. Because of that the retrieved slant column is a differential column, relative to the reference spectrum."

- l. 24: this time is not relevant here

The information might seem irrelevant, but it clearly explains why all the dSCD are zero at this time (e.g. Figure 6, formely 7) and might be useful to understand the simulations of the O_4 dSCD.

- l. 24: optical density of the trace gases

No, the cloud coverage and cloud optical density. If the optical density of the SO_2 was the same, this would mean we are still observing the plume.
clarified.

- p. 38: Eqs. 3 and 4 should be put next to the relevant description. Now they are without context.

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Done.

- The z-dependence of the AMF is not mentioned. In principle, the sensitivity to SO_2 or BrO depends on height. How is this included in the calculations?

The referee is right, the AMF also depends on the altitude profile of the trace gas. This dependency is included by the calculation of the Box-AMF including the aerosols of the plume and the total AMF is calculated as concentration weighted average of the Box AMF. Based on our observations as well as other information, the plume altitude range was assumed to be between 3 and 6 km (Figure 12, formerly 14).
This is clarified in the sections 2.2 and 3.2.

- p. 39, l. 22: similar SCDs: for which gas?

Those relevant for this study: BrO and SO_2.
Clarified.

- P. 40, l. 27: errors → errors in the SCD

Clarified.

- What is the FOV (pixel size) of the CARIBIC DOAS observations, e.g. in Fig. 1?

The instantaneous field of view is 1.9°, the pixel size along the flight route is mainly given by the integration time and the speed over ground of the aeroplane. Here it is 8 sec for the individual spectra that corresponds to ≈ 2 km (80secs and 20km for 10 spectra e.g. Figure1). The field of view is now included in the paper, the resolution along the flight track was already mentioned (P. 39, l. 1).

Sect. 2.3:
- p. 42, l. 8: do you also have to assume the altitude of the SO_2 plume?

Yes, we assumed the SO_2 plume to be at the same altitude level as the aerosol plume (see comment above: z-dependency of the AMF).

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- Eq. 5: symbols and not acronyms should be used in Equations

See previous comment on this topic.

- p. 43, l. 3: LOS > VZA = viewing zenith angle
- l. 3: nadir = 0 deg ? it was 82 deg for CARIBIC DOAS. Please be consistent.

The definition of the LOS was original different for the two instruments, as the satellite community uses a different definition, than those people working with ground based or airborne instruments.
It is now consistent (-90^o = nadir),
equation 5 is changed accordingly: cos(LOS) → sin(-LOS).

- L. 4: how is VCD_{geom} defined?

VCD_{geom} = SCD/AMF_{geom},
included it in the text.

Sect. 3.2: - p. 45, l. 15: please define SCD*.

The stars were removed from the O_4 SCD. See comments to review 1.

- l. 17: where is the cloud information coming from?

Large parts of section 3.2 focus exactly on this question.
For clarification an additional "(discussed below)" is included.

- P. 46, l. 14-15: which MODIS observation? Is TAE=AOT?

Changed to AOT

Sect. 3.3.2:
p. 48, l. 23: where do the high O_3 values arise from?

Following the suggestion of reviewer 1 and the comment of reviewer 2 to shorten the manuscript the discussion of the ozone data was removed.
The high ozone data observed just prior to the first SO_2 peak are caused by a strato-

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spheric influenced air mass (p48 l12).

Sect. 3.4:
AURA > Aura (or EOS-Aura)

Done.

Conclusions:
the last sentence is quite an abrupt end; please make a final conclusion.

A short section on the BrO to SO_2 ratio from the GOME-2 data was added.

Table 1: please also give the SCD and AMF errors in this table.

Done, the table was extended by the errors of the GOME-2 data as well.

Fig. 1: explain the three rows of plots. To which viewing direction do the SCD values relate? Instead of hatching an entire box and making the spectrum less readable, please indicate the wavelength range in a more modest way. This also holds for Fig. 6.

In the caption the spectrometer is clearly mentioned as nadir. Therefore no additional information is necessary here.
It seems the rows are not self explaining? The lowest one shows the fit residual, the BrO-fit is shown in the middle and in the first one SO_2 and O_4 are given for the respective fit interval, while for the BrO interval the OClO fit is shown to illustrate that no OClO is found. It is more clarified in the caption.
A big bar is now used to indicate the GOME-2 retrieval windows instead of the hatched areas in figure 1.
In the figures 5, 8 and 10 the hatched areas were replaced by boxes.

Caption Fig. 13: the caption is wrong: this is not viewing direction, but flight tracks with SO_2 data. Please mention that the figure contains CARIBIC DOAS measurements.

The figure was removed.

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Fig. 15: the yellow points and curve are almost unreadable - please change color.

Done.

Figure captions: please specify the date and time of the observations in e.g. Fig. 6, 7, 9, 10 etc.

The entire paper focuses on data observed 16 May 2010 as mentioned in the abstract and the introduction and at several other places throughout the paper. Is it not boring for the reader to read the date in every figure caption?
Included in the time label of the figures 5, 6, 8, and 11.

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 29631, 2010.