

Interactive comment on “Temporal trends of anthropogenic SO₂ emitted by non-ferrous metal smelters in Peru and Russia estimated from Satellite observations” by M. F. Khokhar et al.

M. F. Khokhar et al.

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Referee 1,

Thanks for raising some important questions about our study. Below you find detailed answers/justifications in accordance to your questions/comments.

Major Points

1) Lengthy discussions about South American volcanoes and smelters

Reply:

Discussions about satellite instrument (section 2), smelters in section (4.2) and South American volcanoes in section 4.6 have been shortened and Table 1 and 3 have been

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excluded as per referee's recommendation.

2) To relate the study of Carn et al., [2007] and Thomas et al., [2005] in more details?

Reply:

A possible relation to Carn et al., [2007] about Peruvian copper smelters has been discussed and updated in the new draft. Some details are as under;

Estimated SO₂ emissions from la Oroya and Ilo smelters during time period of 1996 – 2002 are 0.95±0.07 Tg/yr and 1.09±0.2 Tg/yr, respectively. The extrapolation of the temporal decrease of 25% in the SO₂ VCD (over 6 years, see section 4.4) from Ilo smelter will yield 0.7±0.2 Tg/yr SO₂ emissions in 2005. In contrast, Carn et al., [2007] reported 0.3 (+0.2, -0.1) Tg/yr of SO₂ emissions from Ilo smelter for September 2004 – June 2005, which describes an overall temporal decrease of 72% in combination with GOME observations since 1996. This dramatic decrease might be related to an upgrading of Ilo smelter (by using advance technology as part of the Environmental Compliance and Management Program agreed with the Peruvian government) started in 2004 [SPCC, 2004]. According to SPCC, [2007], the modernization of Ilo smelter completed in January 2007 and resulted in 95% capture of SO₂ emissions on average during 2007. It should be also noted that part of the apparent difference between our data and the results of Carn et al., [2007] is probably be caused by different assumptions on the atmospheric radiative transfer.

However, in case of La Oroya smelter, our calculated trend projects an increase of 20%, while OMI data for La Oroya smelter (0.07±0.03 Tg/yr for September 2004 – June 2005) reported by Carn et al., [2007] combined with GOME data (0.953±0.07 Tg/yr in 2002) indicates an overall temporal decrease since 2002. Reasons for this strong difference are not clear yet.

According to [Boon et al., 2001] about 10 percent of smelters lacking SO₂ emission controls, are mainly from South America, Asia and Africa. Additionally, smelters are

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located in a less studied region with rare available data and literature. However, this difference might be a result of reduction in smelting capacity [Carn et al., 2007] and/or an undocumented modernization (implementation of sulphuric acid plant?) of La Oroya smelter during 2003 – 2005 period.

In general, we conclude that our assumptions made in section 3 are reasonable and especially well suited to investigate trends over the time of GOME observations. However, care has to be taken if results from different satellite instruments using different retrieval settings are compared. Reliable trends from combined time series can probably only be analysed if spectra from the different instruments are analysed with the same retrieval settings.

And about Thomas et al., [2005], we added following text as;

From a sensitive study by applying radiative transfer modeling (TRACY-II) for different wavelengths in the chosen wavelength range (see Fig. 1 under link <http://www.flickr.com/photos/34386593@N03/3198308213/>) it was found that that the errors caused by the exact selection of the wavelength are in the order of 10%. Which is comparable to 15% range stated by Thomas et al., [2005] due to spectral variation of AMF between 315 and 327 nm for 5% surface albedo and $SZA < 60^\circ$. For further details please see response to short comment from W. Thomas.

3) Uncertainty caused by effects of Clouds and Aerosols

Reply:

The uncertainty of individual data points is mainly caused by the effects of clouds and aerosols. We can't apply a good correction for these factors, because the needed knowledge (especially on cloud altitude, SO₂ plume altitude and aerosol properties) is not available for individual GOME observations (Khokhar et al., 2005, 2006). However, Carn et al., [2007] stated minor aerosol effects for measurements from nadir and near-nadir viewing geometry.

Thus we assume that these properties do not change systematically during the years; the related uncertainties cause the scatter of the data points and therefore the uncertainties of the trends can be directly calculated from the linear regression.

In order to check the significance of our calculated trend we used statistical methods and performed regression analysis of our data sets. Our analysis showed that trends calculated from Ilo and La Oroya smelters from Peru are significant while the trend calculated over Norilsk smelters are insignificant. Therefore, linear fits applied to Norilsk data have been replaced by fitting polynomials of 4^o (fits better to temporal variation of data) to both time series and found an almost consistent behaviour for both winter and summer periods. For further details please see response to short comments by W. Thomas and also (see Figure under link <http://www.flickr.com/photos/34386593@N03/3220435326/>).

Minor comments

Following minor points have been adopted accordingly

p 17396, l3: amount => amounts

done

p 17396, l 8: region => regions

done

p 17396, ¶ paragraph of sec. 2: unnecessary general statements, please remove

It has been removed

p 17397, l3 / 4: references not appropriate - paper of Platt et al. 1994 was published before launch of GOME, Wagner et al.2002 deals only with BrO. Replace by more general references, e.g. Burrows et al., 1999 and Wagner et al., 2008

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done

p 1789, air mass factors: it is stated in the text, that an average cloud fraction of 0.3 is assumed. The effect of this assumption depends on cloud top height and cloud optical thickness relative to the assumed vertical profile of SO₂. Did you assume that the SO₂ is completely shielded by the clouds in 30.

No, even for the cloudy part, the SO₂ is not completely shielded although it is assumed to be below the cloud.

p 17399, l 16/17: while the choice of parameters might not influence the trends much, it does have a large impact on the estimated emissions!

It has been mentioned in the new draft.

p 17401, l 16 - 20: Something appears to be wrong with these sentences. Also, I don't think there is much need to explain what polar night is.

It has been corrected

p 17401, l 22: "snow cover extension with in selected region" => snow cover within selected region

It has been corrected

p 17403, 1st para: considering the paper of Carn et al., 2007, the statement on the distinctness of GOME measurements appears out of date

It has been removed from the draft

p 17403, l 12: showed => shows

done

p 17403, l 14: showed => shows

done

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