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Interactive comment on "OMI measured increasing SO$_2$ emissions due to energy industry expansion and relocation in Northwestern China" *by* Zaili Ling et al.

Zaili Ling et al.

jianminma@lzu.edu.cn

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First of all, we would like to thank the reviewer for his/her comments and suggestions which significantly improve the presentations and interpretations in our revised manuscript. Based on the reviewers' comments, we have made major revisions to the manuscript. The revised manuscript and supporting information are attached to Supplement. The reviewers' original comments and our responses are as follows:

This study demonstrates an increasing trend in SO2 over the northwestern region in China, in contrast to a well-established decreasing trend already reported for Eastern China. Shen et al., 2016 presented similar results before, however, here, the au-

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thors perform regression analysis/MK test, and 'a source detection approach to derive source strengths' using OMI-derived SO2 column density. They also report ï¡đ30-50% contribution of SO2 emissions over the two northwestern regions from two energy industrial parks. This work can be accepted for publication upon addressing the following suggestions.

1. A more rigorous and thorough analysis is required to confirm that the OMI-retrieved SO2 column densities can be used to derive/estimate the increasing trend in SO2 emissions/concentrations over these regions. Here, authors use Level-3 SO2 data at a particular spatial resolution with a constant AMF of 0.35. I would suggest a more detailed and in-depth study using the satellite SO2 column density dataset; in terms of AMFs, spatial resolutions, various data filtering methods, sampling, averaging etc. and its impact on the results demonstrated here. This sort of a scientific analysis is required in order to come within the scope of ACP (rather than describing the trend analysis and spatiotemporal pattern of SO2 sources). McLinden et al., Fioletov et al., and Krotkov et al. papers are good references for this. Also, two years of in situ data over 188 sites offer a valuable piece of information (for example, L134:138: representativeness issues should have been addressed/described more carefully) to further test/evaluate satellite data (in addition to the supplementary figure and table). Also, describe in detail how the uncertainties in various datasets impact the results.

Response: As we stated in our paper (line 119-122), we used Level-3 SO2 data at a particular spatial resolution with a constant AMF of 0.36 but the SO2 column density was adjusted by AMF values in China. Following the Reviewer's suggestions, we have rephrased text regarding the satellite data applied in the present study. In revised section 2.1, we introduced more detailed descriptions of the source, spatial resolutions, and potential errors of satellite data (line 86-122). In new sections 2.4 and 2.5, we added more details in the source detection algorithm developed by McLinden et al. and Fioletov et al. The sources of errors in determining the overall uncertainty of the SO2 emission estimation as well as their impact on the results were discussed

(line 219-230). We further added the comments on the causes of the inconsistency between SO2 VCD and monitored data (line 257-278 of the revised manuscript). We have quantified the uncertainties in the SO2 emissions derived from OMI measurements in the two major point sources in northwestern China by running the source detection model repeatedly for 10,000 times using Monte Carlo method. Results show the standard deviation of -35 to 122 kt/yr for SO2 emissions in NECIB and -29 to 95 kt/yr for SO2 emissions in MEIB from 2005 to 2015 which are presented in Fig. 11a and b, respectively (line 219-230 of the revised manuscript)

2. Need to correct for grammatical mistakes throughout the paper (examples; L2: economic growth; L9: reduction of; L127: but the both; L133: such the inconsistence; L200: an significant; 412: desert and Gopi? : : :). Also, loose/empty sentences, and repetitions should be corrected while revising the paper. Change 'SO2' to 'SO2' for all the figures.

Response: We have made every effort to improve language and taken more careful proofreading of the revised manuscript. Those spells and language errors have been corrected (e.g. 'destert and gobi' changed to Gobi desert) . We have changed 'SO2' to 'SO2' in all the figures.

3. L81:82: try avoiding the point no.2, you can mention that, however, it's already an established point?

Response: We thank the Reviewer for his/her suggestion. We have rewritten the second objective of this paper as "identify main causes contributing to the enhanced SO2 emission in northwestern China" (line 81-82 of the revised manuscript).

4. Section 2.1: describe more details of satellite SO2 data, error sources etc. This is the most important part of this paper.

Response: As our above response to the Reviewer's comment, following the Reviewer's suggestions, we have rewritten the description of satellite data (section 2.1).

We also added the source, spatial resolutions, error, and uncertainties of satellite data used in China in this study in two new sections 2.4 and 2,5.

5. L101:118: Better if you describe figures and tables in the results section. Describe just the 'materials and methods' in this section.

Response: Following the Reviewer's suggestion, we have rearranged the structure of Data and Methods section. We added the new section 2.5 (satellite data validation), and moved the discussions on the results presented in Table S2, Figure S1. Figures 2 and 3 were presently presented in Supplement but moved to Data and Methods section following the suggestion from a reviewer.

6. L133:134 skeptical of in situ? So, first, describe the dataset, and associated errors, and then describe your figures/results in that context.

Response: Following the Reviewer's comments and suggestions, in the revised manuscript, we have analyzed the causes leading to the inconsistence between SO2 VCD and monitored data (line 257-278 of the revised manuscript).

7. Column density and emissions are correlated (supplementary figure and table). However, describe briefly why there are not linearly related; also, cite some relevant papers relating column density to emissions and surface concentrations (for example, using atmospheric models).

Response: We thank the Reviewer for his/her suggestion. We have conducted new analysis on the inconsistence between SO2 emission and satellite observations data (line 283-298 of the revised manuscript).

8. L134:139: how about using higher resolutions to address the issues of representativeness? Also, these are loose/empty sentences.

Response: We agree that higher resolutions can reduce errors between SO2 VCD and monitored data. However, given the unavailability of data, only annual average monitored SO2 concentration in Urumqi city can be collected from the official data, which

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is spatially averaged concentration over several monitoring sites across the city. This disagreement is unlikely resulted from the spatial resolution of satellite and measured SO2 data because good agreements between SO2 VCD and monitored concentrations can be seen in other cities. As aforementioned, we have discussed the causes resulting in the inconsistence between SO2 VCD and monitored data in the revised manuscript (line 257-278).

9. L150:153: Those publications report some uncertainty estimates; report them here; and describe your figure in that context; more carefully.

Response: Following the Reviewer's suggestions. We have added the uncertainties of SO2 emission in China, and described Figure 3 (line 293-303 of the revised manuscript).

10. L153:156: revise/avoid this sentence.

Response: This sentence has been rephrased in the revised paper (line 303-306).

11. L157:162: briefly mention the socioeconomic data? GDP? why per capita emissions used?

Response: We have added the detail socioeconomic data in the revised manuscript (line 142-144). In general, higher SO2 emissions are reported in those populated and industrialized regions. The use of per capita emission was to highlight the significance of SO2 emission in northwestern China and the fairness in accounting for SO2 emissions across China.

12. Results and discussion section is disorganized throughout. For the results section, first describe the decreases in SO2 over eastern China (as already reported in earlier publications), and focus more on the northwestern region (regions with increasing trend; this is the novel aspect of this paper?) in a separate sub-section.

Response: Following the Reviewer's suggestion, we have reorganized Results and Discussion section. In subsection 3.1 'OMI measured SO2 in China', we briefly dis-

cussed spatial-temporal distribution and fluctuations of SO2 VCD in China with focus on eastern and southern China. In subsection 3.2 'OMI measured SO2 'hot spots' in northwestern China', we highlighted two SO2 contaminated 'hot spots' featured by increasing SO2 VCDs in two large-scale energy industrial bases. In subsection 3.3 'OMI SO2 time series and step change point year in northwestern China', we extended our discussions and analysis from the increasing SO2 VCD in the two 'hot spots' to entire northwestern China which might be linked with SO2 emissions in those energy industrial bases. To be consistence with the new paper flow in the section, we moved Fig. 8 to subsection 3.1 as Fig. 6.

13. Figure 4: color bar should have the units.

Response: Done!

14. L385:393: describe 'source detection approach' (describe vertical column vs 'burden'; 'emission burden' a rate?) in the method section more clearly; and describe Figure 10/11 here in the results section itself. Better to overlay the column density data in figure 11. Also, a map of column density possible in figure 10 to see it in the context of these burden maps?

Response: Detailed source detection approach has been added to Date and Method section in the revised paper. We also presented detailed descriptions of SO2 emission estimate in new section 2.4. There was an error in previous Fig. 10. In figure caption and corresponding discussions we talked about SO2 emission burden. In the revised paper Fig. 10 shows SO2 VCD. Corresponding discussions were also revised (line 487-494). The estimated SO2 emissions using the source detection algorithm (Fioletove et al. 2015, 2016), VCDs, and their respective fractions are illustrated in revised Fig. 11.

15. L462: mention about Particulate Matter (PM) in the introduction section itself.

Response: We have deleted this phrase.

Please also note the supplement to this comment:
http://www.atmos-chem-phys-discuss.net/acp-2017-161/acp-2017-161-AC3-supplement.zip

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