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Interactive comment on “Regional differences in Chinese SO₂ emission control efficiency and policy implications” by Q. Q. Zhang et al.

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This is a sensitivity study on the efficiency of different regional SO₂ emission control scenarios in reducing sulfate pollution in China. The authors ran GEOS-Chem chemical transport model for 4 different emission reduction scenarios, all of which cut the overall SO₂ emissions from China by 8% from the 2010 level but distribute the reductions differently. In one scenario, the SO₂ emissions are cut uniformly over the entire country, while in the other three scenarios, the reductions are limited to three main source regions (North China, South China, and Southwest China). The authors then compared the resulting reductions in national average sulfate, population-weighted sulfate, and export of sulfur (SO₂ + sulfate) to the West Pacific for different scenarios,

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and concluded that controlling SO₂ emissions from North China will have the greatest benefit in terms of reducing national average sulfate and export of sulfur species, while controlling SO₂ emissions from South China will have greater benefit in reducing population-weighted sulfate concentration. Sensitivity tests were also conducted to investigate the effects of meteorology and the amount by which SO₂ emissions are reduced on the conclusion. Overall, this is a well-designed study with interesting results that may have some implications for pollution control strategies for China. The writing is understandable (although can still use some improvement) and the figures are mostly clear. I feel that the paper would be suitable for publication in *Atmos. Chem. Phys.* after the following comments have been addressed.

Specific Comments: 1. The authors compared the model simulated AOT, sulfate, and sulfate deposition with measurements, but only briefly mentioned the regional comparison results for AOT, which is not a direct measurement of sulfate. I wonder if the authors can comment on the regional biases in modeled sulfate and how the biases can affect the conclusions of this study. Response: The reviewer's point is well taken. In the original paper we compared simulated sulfate with measurements at one surface site located in North China. The question of concern here is whether the model bias differs by region and if so, what is the implication for our conclusions. To address this question, we've added model-measurement comparisons at another two sites: Jinsha located in South China and Chengdu located in Southwest China. The model has an annual mean bias of 5% at the Jinsha site and -8% at the Chengdu site (new Figure 5b and c), although seasonal biases are higher partly due to the fact that the simulation and measurements are for different years. By comparison, the annual-mean bias at the Miyun site is 4%. Since the annual mean model biases are consistently within $\pm 10\%$ for the three regions of interest, we argue that the regional biases in modeled sulfate will not affect the conclusion of our paper. Please refer to the new Figure 5 and the revised Section 2 in the revised manuscript.

2. Again, AOT over China can be affected by a number of factors such as dust

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and humidity. Have the authors looked into other satellite datasets such as SO₂ for model evaluation? Response: We have conducted additional model evaluation using total SO₂ columns from the OMI satellite instrument. Compared to AOT, satellite-derived SO₂ columns provide a more direct evaluation of sulfur simulation in the model since SO₂ is the direct precursor of sulfate. The original horizontal resolution of the Level 3 OMI data is $0.25^\circ \times 0.25^\circ$, and the GEOS-Chem simulation has a resolution of $0.5^\circ \times 0.667^\circ$. We regridded both OMI and modeled SO₂ columns to $1^\circ \times 1^\circ$ resolution for comparison. The spatial distribution of SO₂ column densities from GEOS-Chem correlate well with those from OMI, with the correlation coefficient being 0.79, 0.73 and 0.64, for NC, SC and SWC, respectively. Compared with the OMI SO₂ retrievals, GEOS-Chem simulated SO₂ columns are 6% higher in NC, 2% higher in SC and 8% lower in SWC. The discrepancy between the modeled and OMI SO₂ is within $\pm 10\%$ for all the three regions, indicating an overall good simulation of SO₂ by the GEOS-Chem model. Please refer to the revised manuscript Section 2 and new Figure 3.

3. I understand that this is merely a sensitivity study, but can the authors comment on the actual SO₂ emission change during and/or before the study period (given that the emission inventory seems to be available for multiple years)? How do the actual national/regional trends compare with the different scenarios tested in the study? Response: We have included relevant discussion in Section 5 of the revised manuscript. In this study, we recommend that SO₂ emission control over NC should be stressed to maximize the air quality benefits for China and downwind regions. However, from 2006 to 2010 (the 11th Five-Year-Plan period), SO₂ emissions from NC have decreased at a much slower rate than the national total emissions. Based on the MEIC inventory, total SO₂ emissions from China were 9.4% lower in 2010 than 2006, and emissions from NC, SC and SWC have decreased by 4.7%, 16.1% and 23.1%, respectively, during the same period. The relative reduction of SO₂ emissions in NC is thus one third or less of that for the other two regions and is only half of the reduction at the national mean level. This indicates that China has not prioritized SO₂ emission control in NC in the past. Our study suggests this should be corrected in the future in order to maximize

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the benefits of SO₂ control. Please refer to the revised manuscript in Section 5.

4. I assume that the population weighted sulfate concentration can be calculated on a grid-box basis instead of for each province – by weighing the sulfate concentration with a ratio between population density in each grid box and the national average population density? Some provinces seem to be in more than one study region and that may lead to uncertainty in the population-weighted sulfate. Response: Actually, even if one or two provinces are in more than one study region, this will not lead to uncertainty in our calculation of the population weighted sulfate concentration (PWC) for each region. This is because our calculation is based on individual model grid boxes rather than provincial boundaries. We first multiply sulfate concentration by population in each grid box within a region, then sum them up, and finally divide the sum by the total population within the region. As the reviewer suggested, if we calculate the PWC by weighing the sulfate concentration with a ratio between population density in each grid box and the national average population density, the PWC will not be at the same order of magnitude with surface sulfate concentration because the population density at some grid boxes is tens of times greater than the national mean population density. We clarified this in the revised manuscript.

5. Can the authors comment on the seemingly larger bias in the modeled sulfate for the second half of the period covered by Figure 3a? Response: The larger bias of the model during the late spring and summer can be explained by the model's weakness in simulating large precipitation and high wind speeds at the local scale (Zhang et al., 2012, Wang, Y. et al. 2013a). We have added a discussion on this issue (Section 2 in the revised manuscript).

6. It will be useful to mark the scenarios for Figures 4b and 4c. Response: We have marked the scenario names in the figures. Please refer to the new Figure 6b and 6c.

7. Can the authors point out where the “other regions” in Figure 6b are? Northeast China? Response: Not only Northeast China, but all the rest Chinese regions as well

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as global influence. We clarified this in the new Figure 8b.

8. Can the authors provide an explanation for the more dominant role of gas-phase photochemistry for North China than South and Southwest China? Less humidity? Stronger NO_x emissions? Also how does the presumably stronger washout (and shorter lifetime) in the southern part of China affect the conclusions of the study? Response: The lower atmospheric humidity over NC will inhibit the aqueous phase oxidation, while the stronger NO_x emissions from NC will result in higher OH concentrations and thus enhance the gas phase oxidation. Both factors are responsible for higher percentage of gas phase SO₂ oxidation over North China. The shorter lifetime of sulfate over SC and SWC makes it harder to transport over long distances to downwind regions, so it is another reason why SO₂ emission control from NC has the largest efficiency factor in reducing national mean surface sulfate concentration. We have added these two points in Section 4, please refer to the revised manuscript.

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