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Geoscientific Model Development Discussions

Interactive comment on "The air quality forecast of PM₁₀ in Beijing with Community Multi-scale Air Quality Modeling (CMAQ) system: emission and improvement" *by* Q. Wu et al.

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The authors thank the editor and the reviews for their encourage and the constructive and up to point comments. Our detailed replies to the referee comments are given below.

1 Reply to Referee #1

We thank the referee share his time to give the constructive suggestions. Our detailed replies are given below.

1.1 Comment from Anonymous Referee 1

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Suggestions were given below, 1) Section 3.3: why have you added more point source emissions in the surrounding areas of Beijing? Just for the improvement of your simulations? 2) Section 3.3: More point source emissions were added and the area emissions were updated in the original domain D4 or in the expanded Domain D4? 3) Please add the simulations in Figs. 7, 8, and 9 only when domain D4 was expanded, more point source emissions were added, and the area emissions were updated, respectively? 4) Please add the simulations when more point source emissions were added and the area emissions were updated but domain D4 was NOT expanded. 5) If possible, please add the WRF-Chem model simulations when more point source emissions were added and the area emissions were updated but domain D4 was NOT expanded. 6) Please add the implications of your research. 7) English still needs improving.

1.2 Respond

Comment: 1) Section 3.3: why have you added more point source emissions in the surrounding areas of Beijing? Just for the improvement of your simulations?

Reply: Yes, the added more point source emissions in the surrounding areas of Beijing is used for the improvement of the simulation. Besides that, the area emissions in Baoding and Tangshan has been also increased for the model improvement, and

the total emissions in two cities are according to the emission report in (Compilation Committee of China Pollution Source Census, 2011)().

As described in the fouth paragraph of section 2.4.2 in the manuscripts, there are only 418 point source emissions in Hebei province in the forecast system, only including the main industrial emissions. In this study, we have collectted more point source emissions in Baoding, Tangshan and Langfang Municipality, a total of 4405 point source emissions, and shown in section 3.3 and Fig. 4 in the manuscripts. Those added point source emissions includes industrial, commercial and other catalogs. As we known, the point source has more accurate location, and the more point source emissions would give more accurate on the emissions distribution, which is important in the simulation of air quality.

With the model sensitivity test, we found that the updated emissions can improve our model performance, including the model performance in the surrounding areas. Here we present the model improvement in Baoding, Tangshan and Xianghe stations, which are located at Baoding, Tangshan Langfang Municipality, and the station map is shown in **Fig.1**. The observation is from the Beijing-Tianjin-Hebei Atmospheric Environment Monitoring Network operated by the Institute of Atmospheric Physics, Chinese Academy of Sciences(), and coveres the air pollution episode menioned in the manuscript. As described in the left figure of Fig.2 in the manuscript, the original domain D4 just covers Beijing Municipality, that Baoding, Tangshan and Xianghe station is either outside or nearby the domain boundary, thus, we design a group model sensitivity test in the "New" expanded Domain D4, to check if the "added" point and area sources emissions would improve the model performance on the surrounding areas. The model results driven by the forecast emission have been compared to the model results presented in the manuscript, which is driven by the updated point and area sources emssions in the same "New" expand domain D4. With this set of comparison, we can get the model performance on Beijing's surrounding areas, and get the model improvement due to the emissions updated.

The scatter plot and quantile–quantile (Q–Q) plots are used to illustrate the model performance, The "blue" points are driven by the forecast emission in the "New" domain, the "pink" points are driven by the updated emission in "New" domain, while the "Red" line is the model perfect line "y=x". The Q–Q plots are introduced by Chang et al.(2004) (), and used to compare the concentration distributions between the simulations and observations, with the Q–Q plots, biases at low or high concentrations are quickly revealed. As shown in **Fig.2**, the CMAQ model has obviously better model performance in Baoding and Xianghe station, and a little model improvement in Tangshan station: the pink simulated–observed points in Baoding and Xianghe stations are much closed to the red line "y=x" than the blue ones according the left scatter plots. With the Q–Q plots in **Fig.2**, we also can found that the CMAQ model has better performance in both the high and low concentration range, and get better distribution on PM10 hourly concentration. The mean bias(MB), mean error(ME), FAC2 and normalized mean square error(NMSE) are calculated and shown in Table. 1. Consistent with the scatter plots and Q–Q plots, the statististical measures indicate the model performance improved obviously in Baoding and Xianghe stations, that their FAC2 increases from 16% and 23% to 33% and 48% respectively while the NMSE decreases from 4.258 and 3.064 to 2.702 and 1.367.

As shown in the plots and statistical parameters, after the point and area sources emissions updated, the model performance improved obviously, especially in Baoding and Xianghe stations. But we also can found that the model performance of PM10 hourly concentration in Beijing's surrounding areas, is poorer than that in the Beijing, which the FAC2 of the hourly concentration reach to 74% and NMSE decreases to 0.190, which is mentioned in section 3.4.2 in the manuscript. There may be two reasons: first, the emissions in the surrounding area maybe still underestimated, that the Q–Q plots show that the model underestimates the PM10 concentration in both high and low concentration range in the three surrounding stations. Second, the model domain may need to be expanded much bigger if we want to get much better model performance in the surrounding area, for example, if we want to get much better model performance

Table 1. Statistical measures for PM10 hourly concentration in Baoding, Tangshan and Xianghe stations, which is located at Beijing's surrounding areas. The "rEmis" is mark that the model results driven by the forecast emission and the "New" is mark the model results driven by the updated emissions.

	Baoding		Tangshan		Xianghe	
	rEmis	New	rEmis	New	rEmis	New
MB	-208.22	-182.95	-121.69	-111.52	-141.73	-103.68
ME	209.53	187.42	133.07	130.25	143.00	117.07
FAC2	16%	33%	38%	35%	23%	48%
NMSE	4.258	2.702	2.549	2.036	3.064	1.367

in Baoding Municipality, may we need to expand the model domain to cover Baoding's surrounding areas, e.g. Shijiangzhuang Municipality. Both of the two reasons need to be more in-depth analysis in the future study.

In the end, because this manuscript is focus on the simulation in Beijing, the model performance in the surrounding areas mentioned above will be present in the supplement materials to support this manuscript.

Comment: 2) Section 3.3: More point source emissions were added and the area emissions were updated in the original domain D4 or in the expanded Domain D4?

Reply: As memtioned aboved, "more point source emissions" and the area emissions were updated in the expanded domain D4.

Comment: 3) Please add the simulations in Figs. 7, 8, and 9 only when domain D4

was expanded, more point source emissions were added, and the area emissions were updated, respectively?

Reply: Thank you for your comment. The work of adding more point sources emission and updating the area source emissions are both to update the emission to improve the model performance. And we mark the emissions before updating as "Forecast Emissions" and the emission after updating as " New Emissions", according this comment from the referee, we try to add two simulations in Figs 7, 8 and 9 only when domain D4 was expanded, and only when the emissions updated, and present in the followed.

Base on the time series plot "Fig. 7" in the manuscript, we add two simulations: 1) the "added" blue dashed line is the model results driven by the updated emission without expanding the model domain, which is only updating the emissions, including point and area source emissions; 2) the "added" green solid line is the model results driven by the forecast emission in the "New" expanded model domain, which is only expanding the model domain.

As shown in **Fig.3**, the "blue dashed" line is similar to the "green dashed" line, which is the model results in the forecast system. The peak of the PM10–API in the "blue dashed" line is about 105, just a little improved than the forecast system results("green dashed"). Compared the "blue" and "green" dashed lines, they used the same model domain but different emissions, the "blue dashed" used the updated emission. It illustrates that the emission updated only can improve the model performance a little without expanding the model domain.

But, compared the "green solid" line and the "blue solid" line, the two model results also used the same model doman but different emissions, the "blue solid" used updated emission while the "green solid" used the original forecast emission in the same "New" expanding model domain, we can found that the "blue solid" line has obviously better model performance than the "green solid" line, and the peak of the "blue solid" reaches to 180, much closer to the observed "red solid" line than the "green solid" line, which

peak is about 140 as shown in **Fig.3**. It illustrates that the same emission updated can improve the model performance obviously than the original forecast emissions in the expanded model domain.

With the two group comparison("dashed" and "solid") mentioned aboved, we can found that effect of emission updated will be obvious in the suitable model domain, as the expanded model domain in our manuscript.

We also add the two simulation into Figs. 8 and 9 according to the comment, and show in **Fig.4** and **Fig.5**. The similar to the discussion aboved, the model performance is better in the expaned domain, no matter the original forecast emissions and the new updated emissions, and the effect of emission updated wil be obvious in the expaned domain for the CMAQ model.

But we also can find that there will be too many color "point" in **Fig.4** and too many color "line" in **Fig.5**, thus, in our optinal, the added model results will be present as supplement materials, and mentioned it in the manuscript.

Comment: 4) Please add the simulations when more point source emissions were added and the area emissions were updated but domain D4 was NOT expanded.

Reply: Thanks for the comment, the simulation, when the more point source emission added and area emissions updated but domain D4 was NOT expanded, is mark as "NewEmis+FDomain(CMAQ)" in **Fig.3**, **Fig.4** and **Fig.5** and discussed aboved.

Comment: 5) If possible, please add the WRF-Chem model simulations when more point source emissions were added and the area emissions were updated but domain D4 was NOT expanded.

Reply: That is a good suggestion, we thanks the referee for this comment, this com-

ment help us to make clearly about why the model underestimated the PM10 concentration during this typical episode.

Because, we have no enough experince on the WRF-Chem model, but in the air quality Ensemble Air Quality Forecast System for Beijing (EMS-Beijing), there are another air quality model CAMx, which is developed by ENVIRON International Corporation(). In the past month, we collected the forecast model results of CAMx model during the air pollutant episode in January 2010, as the blue dashed line shown in **Fig.6**. The CAMx model also underestimated the PM10 concentration when the episode occure, and the peak of PM10-API forecast by CAMx model is 113, better than CMAQ model but also underestimated much.

We also added one simulation using CAMx model, which is driven by the "New" updated emissions, including more point source emission added and area source emissions updated, but in the forecast domain, whose domain D4 was NOT expanded, as the comment from the referee. The model results are also shown in **Fig.6** as "the blue points-line with trianle", we can found that the model performance improve obviously, and the peak of PM10-API reaches to 170, much better than "Forecast(CAMx)", and also much better than its brother model, CMAQ, with the same emissions and model setup. The most possible reason is that the CMAQ v4.4 model use one-way nested technology while the CAMx v4.4 model use two-way nested, and the added surrounding emissions can effect the Beijing's stations more effectively. To make sure this reason, more in-depth analysis will be taken in the future study.

Further more, we added another CAMx model simulation, drive the model with the updated emission in the "New" expand domain. As shown in **Fig.6**, the peak of PM10-API in the blue solid line with "New" emission and "New" domain would reach to 181, closer to the observation, that is better than the blue points-line, which driven by the "New" emission in the original forecast domain.

Because this manuscript focus on the PM10 forecast with CMAQ model, but the CAMx

model results mentioned aboved will point out a possible reason why the CMAQ model underestimate the peak during the episode, the CAMx model results will present as supplement materials to support this manuscript.

Comment: 6) Please add the implications of your research.

Reply: Thanks for this comment, we will try our best to add the implications in the revision according to the comments from the reviewers and referee.

Comment: 7) English still needs improving.

Reply: Thank you for this comment. The English copy-editing is required to help us to improve the English presentation, before that, we will try our best to improve the English presentation, and check the grammatical and syntactic errors as we can.

References

Compilation Committee of China Pollution Source Census I, The pollution source census data set(statistic), Collected works about The first China pollution source survey data(V), China Environment Science Press, Beijing: 228-245, 2011.

Xin J Y, Wang Y S, Tang G Q, Wang L L, Sun Y , Wang Y H, Hu B, Song T, Ji D S, Wang W F, Li L and Liu G R: Variability and reduction of atmospheric pollutants in Beijing and its surrounding area during the Beijing 2008 Olympic Games, . Chinese Sci Bull, 55: 1937−1944, doi:10.1007/s11434-010-3216-2, 2010

Chang J. C, Hanna S. R: Air quality model performance evaluation. Meteorol. Atmos. Phys., 87:167–196, 2004

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Please also note the supplement to this comment:

http://www.geosci-model-dev-discuss.net/7/C1116/2014/gmdd-7-C1116-2014-supplement.pdf

Interactive comment on Geosci. Model Dev. Discuss., 7, 3403, 2014.

Fig. 1. The location of Baoding, Tangshan and Xianghe stations are shown as “green tringle”. They are all in the Beijing’s surrounding areas, where more point sources have been added in this paper.

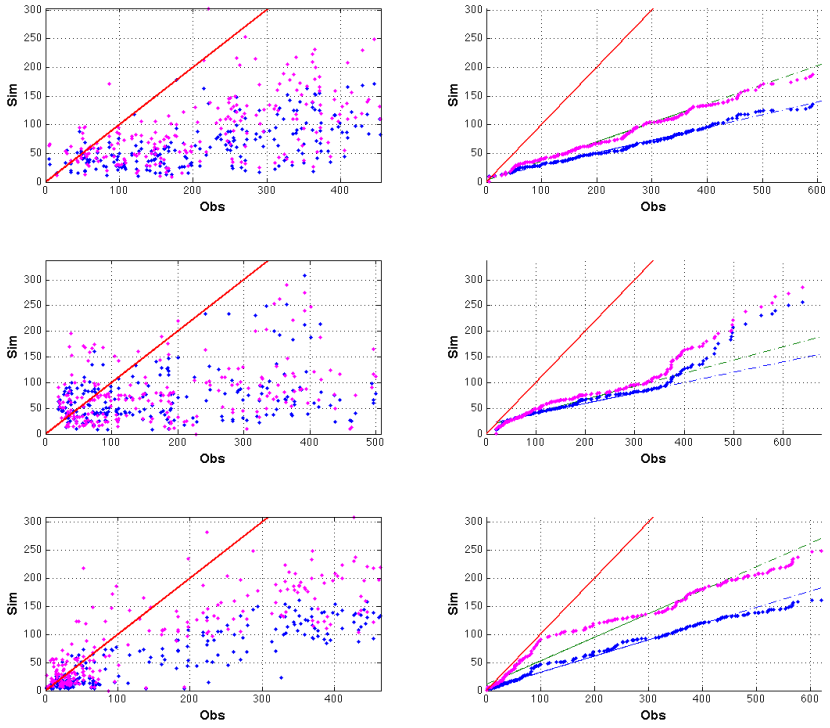

Fig. 2. The scatter plot and quantile–quantile (Q–Q) plots of the observed and simulated PM10 hourly concentration. The upper is Baoding, the middle is Tangshan, the lower is Xianghe.

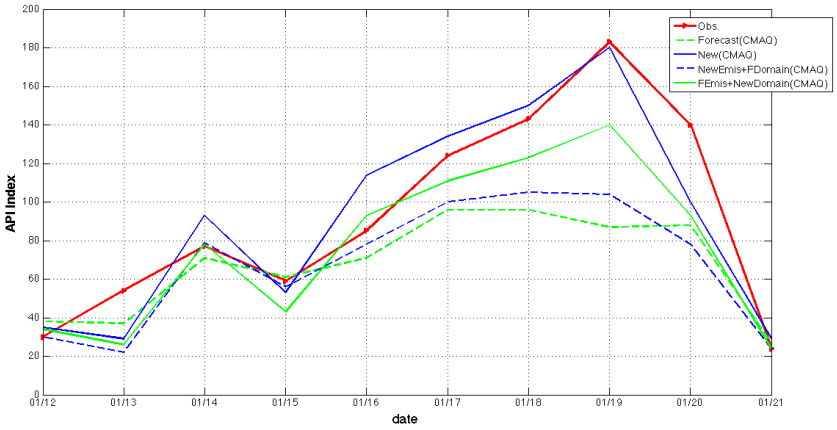

Fig. 3. The time series of the averaged PM10-API in the NSAQ stations in Beijing urban area. Red solid is observation, "added" blue dashed is only updated emissions, "added" green solid only expanded domain.

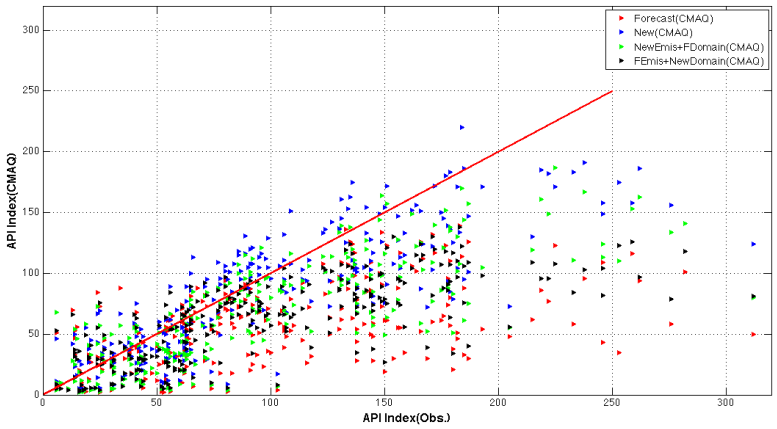

Fig. 4. The scatter diagram of the observed and simulated PM10-API in all stations in Beijing. The "added" green triangle is only updated emissions, and black triangle only expanded domain.

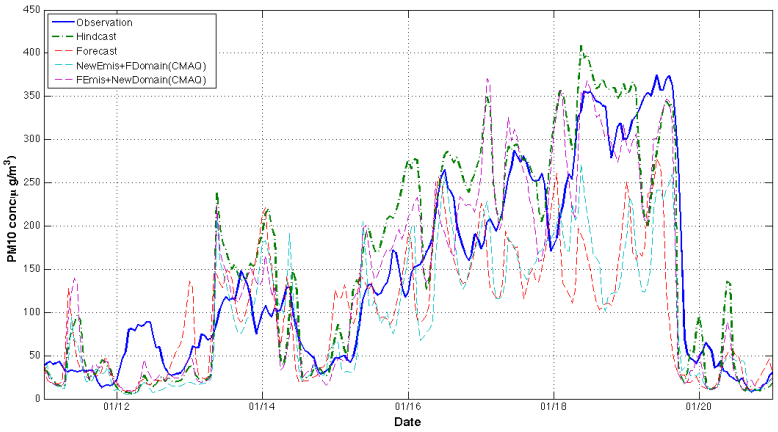

Fig. 5. The time series of the PM10 hourly concentration during the air pollution episode in January 2010. The "added" cyan dashed line is is only updated emissions, and magenta dashed only expanded domain.

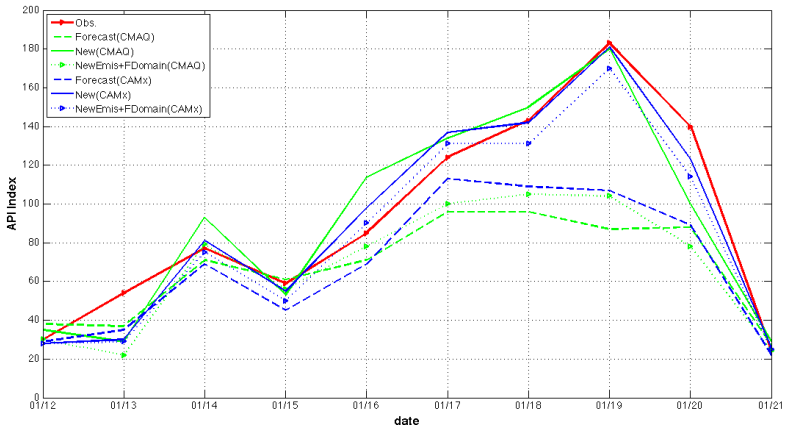

Fig. 6. The time series of the averaged PM10-API in the NSAQ stations in Beijing urban area. The red solid line is the observation, the green lines is the CMAQ model results and the blue is the CAMx model.