

Answer to the comments by #1 Referee

General Comment: *More quantitative discussion based on a statistics analysis recommended, because it seems that model intercomparison is the main purpose of this paper. In addition, more detailed information about observation and model's differences is necessary.*

Since the purpose of this paper is to elucidate the essential element causing the different output for O₃, and not to discuss the superiority or inferiority of the models, quantitative comparison among the models and with observation are not made. Such quantitative discussions have been made in the overall intercomparison paper for O₃ by Li et al. to be submitted in this special issue. However, some more information on the difference with observation has been added according to the suggestion of the reviewer.

L65: *What is the difference between “mixing ratios of surface ozone” and “concentration of ozone”? Both of “mixing ratio” and “concentration” are mixed in the manuscript.*

In principle, ppb, ppm etc. should be called “mixing ratio” and $\mu\text{g}/\text{m}^3$, mol/L, etc, should be called “concentration”. However, the quantity in ppb unit is sometimes customary called “concentration”. In this paper, we use only the unit of “ppbv”, so that we unified the terminology to “mixing ratio” in order to void mixed use.

L79-82: *Why the vertical structures are different among the three models, nevertheless the meteorological fields were derived from the same WRF output?*

Although WRF fields are common to the three models, convective model for boundary layer is different between CMAQ and NAQM, and some parameters within the module are different between the CMAQ v. 5.0.2 and v.4.7.1, which causes the different vertical structure of O₃.

L87-88: *It is introduced that every model adopted MIX. However, the predicted O₃ seems to be affected if the ratio of NO/NO₂ in NO_x emission and the speciation of VOCs emission were not unified in the model-ready emission input.*

Among the three models, NO/NO₂ ratios in NO_x emission are set commonly as 0.9. Speciation of VOC is the same for the CMAQ v.5.0.2 and v.4.7.1 since they used the common chemistry sub-model, SAPRC99, but it is different from NAQM which employed CMB-Z. Yes, it is true that the difference in speciation and reaction mechanism causes the difference in predicted O₃ as discussed in the first part of Discussion.

L91: *What is the reason for using two global models for the intercomparison study?*

Each modeler wants to use accustomed global model for providing the boundary for easiness. Reflecting such request of participating modelers, the project accepted to use either of the two global models after confirming their output does not differ much in East Asian region (page 3, Lines 88-90).

L105: *I guess CMAQ v4.7.1 does not include AERO6. It may be up to AERO5.*

Yes, the reviewer is right. CMAQ v.4.7.1 includes AERO5. Line 102 has been corrected.

L115-116: *Only monthly averaged diurnal variations are introduced for a model evaluation. A table of statistics for hourly comparison (including mean observation, mean simulation, normalized mean bias, correlation coefficient in different season and whole observation period) seems to be necessary, and the discussion should be more quantitative because model intercomparison is the main purpose of this paper.*

As noted above in the answer to the general comments, the purpose of this paper is not for the so-called model intercomparison per se, but for trying to identify the possible model elements that causes much different outputs of O₃ concentration even though using the common emissions, meteorological fields and boundary conditions. The quantitative statistical analyses have been made in the overall intercomparison paper by Li et al. for the submitted all models including the three models in this paper.

L139-140: *More details about the observation conducted by IAP are necessary (e.g. monitoring equipment, height of IAP tower and its location).*

More detailed information on the observational sites and equipments by IAP has been added on page 5 (Lines 140-147) as follows.

“The O₃ and NO_x instrument at IAP site (39.9N, 116.3E) were on the rooftop of a building (8 m above the ground), which is a urban site surrounded by residential infrastructure and freeway in the east (360m). Yangfang (40.2N, 116.1E) is a suburban site in the north of Beijing, 40 km away from IAP. The instruments were 10 m above the ground on the campus of a university with little influence by local sources and sinks. The O₃ and NO_x instruments were an ultraviolet photometric analyzer (Model 49i, Thermo Fisher Scientific (Thermo)) and a chemiluminescence analyzer (Model 42i TL, Thermo), respectively.”

L158-159: *Since information about the location of each site in Beijing are not introduced, it cannot be determined that the predicted results can be compared with the observation or not.*

We agree that more detailed information of the referred sites in Beijing is necessary. We added explanation of the sites in page 5 (Lines 147-153) as follows.

“One of the referred Beijing data is the monthly averaged daily maximum concentration of O₃ in April and July in 2014-2015 averaged over two suburban sites, Daxing (39.7N, 116.4E) and Shunyi (40.1N, 116.7E) presented by Chen et al. (2015). Another data is the averaged diurnal variation at three urban/suburban sites, Fengtai, Shunyi and Baolian, in July and August in 2007, which are given in the paper by Xu et al. (2011). All the denoted observational sites in Beijing are located within the selected nine model grids shown in Fig.1.”

L237: *What is the definition of “net chemical production of O₃”? How did you calculate it? If it is just the difference from the concentration in the previous time, I guess transported O₃ is also included in the net chemical production.*

We added the definition of “net chemical production of O₃” explicitly in the text as follow on page 8 (Lines 251-256).

“Here, the net chemical production, $N(O_3)$, is calculated by the equation, $N(O_3) = F(O_3) - D(O_3) = \{k_1[HO_2][NO] + k_2[RO_2][NO]\} - \{k_3[O(^1D)][H_2O] + k_4[OH][O_3] + k_4[HO_2][O_3] + k_5[O_3][olefin]\}$ in NAQM. The CMAQ models give the net chemical production as the difference of O₃ mixing ratio between the calculation steps of chemistry module with a

process analysis package. The net chemical production was calculated in each grid and then average was taken for all the selected grids.”

L321: *Is “process analysis” also used for the calculation of “net chemical production of O_3 ”?*

In this paper, the term of “process analysis” includes the evaluation of vertical and horizontal transport, surface deposition and net chemical production.

L322: *It is recommend to prove “the horizontal transport has been found to be nearly the same for the three models” in this manuscript.*

The horizontal transport at each region in spring and summer has been evaluated, and it has been found there is not much difference among the three models. This is possibly due to the fact that horizontal transport is mainly controlled by the WRF fields, which are common to all three models. In order to reduce the number of figures, the graphs for the comparison of horizontal transport was not included in the paper. The text is slightly modified as follows for clarification (page 11, Lines 341-343).

Original version: Since the horizontal transport has been found to be nearly the same for the three models, only the vertical transport will be discussed here for discussion.“

Revised Version: “Since it has been found that there is not much difference in horizontal transport and surface deposition, and the chemical mechanisms of CMAQ 5.0.2 and CMAQ 4.7.1 are the same, the difference in the model performance must be ascribed to the difference in vertical transport processes.”

L333: *I am afraid, but the discussion is unclear about a reason why only CMAQv5.0.2 reproduced largest downward fluxes of O_3 .*

The difference between CMAQ 5.0.2 and 4.7.1 in the treatment of vertical transport of O_3 has been clearly stated in the Methods, and included in the discussion. The added sentences are as follows.

“For the computation of the vertical transport for advection, CMAQ 5.0.2 used PPM (piecewise parabolic method) scheme, as compared to CMAQ 4.7.1 and NAQM which used the vertical velocity directly from WRF.” (page 4, Lines 109-111)

“Here, it should be noted that the vertical transport was computed in the PPM scheme in CMAQ 5.0.2 instead of the direct extraction from WRF in CMAQ 4.7.1 as described in the section of Methods. The PPM method has been known to introduce more downward flux of O₃ from higher layer to the surface layer. “ (page 12, Lines 361-365)

L349-350: *Why could you conclude that “the difference in the model performance must be ascribed to the difference in transport processes”?* Sorry, but discussion is unclear on it.

The difference in the two models (CMAQ v.5.0.2 and CMAQ v.4.7.1) should be due to either of the processes: vertical transport, horizontal transport, surface deposition, and chemical processes. Among them, as noted above, there is not much difference in horizontal transport and surface deposition, and the chemistry model is the same for these models. Therefore, we concluded that the difference in the model performance must be mainly ascribed to in the vertical transport process. The sentence is slightly modified for clarification as follows (page 11, Lines 341-344).

Original version: “Since the horizontal transports in the selected regions and seasons have been found to be nearly the same for all the three models, only the difference in the vertical transport will be discussed here.”

Revised version: “Since it has been found that there is not much difference in horizontal transport and surface deposition, and the chemical mechanisms of CMAQ 5.0.2 and CMAQ 4.7.1 are the same, the difference in the model performance must be ascribed to the difference in vertical transport processes.”

Fig. 2 (a): *Please modify “Mixing Raio” to “Mixing Ratio”.*

Thank you for alerting. We corrected the miss spelling.

Fig. 5 (b): *Please modify “ppb/hr” to “ppbv/hr”.*

Thank you for alerting. We corrected the miss spelling.

Fig. 7&8: *What is the difference between “mixing ratio” and “concentration”?*

Thank you for alerting. We unified them to “mixing ratio”.

