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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Quantifying pollution inflow and outflow over East Asia through coupling regional and global models" *by* M. Lin et al.

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Author Response to Anonymous Referee 1

We are grateful to the reviewer for his/her constructive comments that we believe have helped us to strengthen the manuscript. Below we include the original review, and we respond to each comment line-by-line. Original reviewer's comments are shown in black, and ***our response in bold***.

Overall comments: In the paper two regional models (WRF-Chem and CMAQ) are coupled to a global model (MOZART). The focus of the paper is on export events from East Asia, and on import of air pollutants from Europe (in the regional model the import

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is derived using lateral boundary concentrations from the global model.

The paper convincingly shows that the regional models give a more detailed (and improved) description of the outflow from the Asian continent compared to the global model. The improvement is attributed to better resolution in the regional models, but also to an inability to capture deep convection events in the global model. As stated in the paper, the parameterization of convection should be improved in the global model, and this may to some extent change the conclusions somewhat, as this may result in pollution plumes being lifted to higher altitudes.

Results from a large set of models, including the MOZART model, have been uploaded to the HTAP server in Julich. In the HTAP companion papers/reports (see below) it is showed that the calculated range in import/export to/from the main continents differs substantially between these individual models. Here the regional models are compared to just one of these models. The authors should comment on how the export in and out of East Asia from the MOZART model compares to other global models, and the possible effects any model updates since the time when the HTAP model results were submitted. An interim report and several papers have been published within the framework of HTAP. The authors refer to most of them, but not all.

» We have added discussion on export uncertainty based on the CO vertical profiles from 10 HTAP global models (P13, L5-20):

"We also looked at the vertical profiles of CO at three stations along the East Asian coast from 10 global models providing vertical profiles for intercomparison and evaluation with ozonesonde observations [Jonson et al., 2010]. It appears that none of the HTAP global models captured the strong upper-troposphere (6-9 km) CO outflow simulated in WRF-Chem for the 7-March episode (figure not shown), but there is a significant variability of CO vertical profiles among models for the other four frontal episodes shown in Figures 2 and 3. Among the HTAP global models, MOZECH, CAM-Chem, and CHASER

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show relatively greater CO outflow to the free troposphere than others. Some events suggest MOZART is on the high side of altitudes and others in the low side, suggesting a real need for more process oriented studies. Jonson et al. [2010] examined the vertical profiles of O3 from the HTAP global models. They found a similar spread in the modeled vertical profiles of O3 and the agreement between ozonesonde measurements and individual models tends to be at its minimum in spring and summer. The timing and location of pollution plumes may vary among models, but vertical profiles are only available at the individual stations at 12-h intervals and a detailed comparison of HTAP global models is beyond the scope of this study."

Specific comments: Page 1: Introduction A description of intercontinental transport in and out of East Asia (and other regions) is included in the HTAP interim report and partially also in companion HTAP papers. References to these publications could be included in the text here.

Page 112, lines 8 - 22 Calculated effects of transport to North America and to EAST Asia are also discussed in the companion HTAP papers, and results from these papers could be included in the discussion here.

Page 113, line 7 Surface ozone, aerosols and oxidised N deposition also included in TF HTAP (2007).

» The HTAP model intercomparison and references to its companion papers are introduced in the third paragraph of Introduction (P3, L9-35). We added the references to Jonson et al. (2009) and Shindell et al. (2008), and briefly discussed the results from the companion HTAP papers (P3, L24-28):

"Most pertinent to our study are the findings that 8-15% of emitted NOx is transported over 1000 km from the source region boundaries [Sanderson et al., 2008], sub-continental scale variability in O3 response to foreign emission changes [Reidmiller et al., 2009] and the wide range in model estimates for EU influence

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on EA O3 in spring (over a factor of 2) [Fiore et al, 2009].”

Page 113, line 10 The Ellingsen et al. (2008) paper is based on a different dataset than HTAP.

» Agreed, but Ellingsen et al. (2008) also evaluated the impacts of intercontinental O3 transport on agricultural crops. To clarify, we rephrased the sentence as (P3, L28-32):

“Continental-scale average estimates of the surface O3 response to foreign emission changes from the global coarse-resolution models have been used to assess the impacts of intercontinental transport on human health, mortality and crop productivity [Ellingsen et al., 2008; Casper-Anenberg et al., 2009], and will inform global air pollution policy.”

Page 115, line 24 How often were the chemical boundary condition updated?

» We have clarified the frequency of boundary conditions. The sentence (P5, L16-18) now reads: “Each regional model was run twice, with temporal varying (hourly for CMAQ, 6 hourly for WRF-Chem) chemical boundary conditions from the MOZART base and SR6EU simulations, respectively”.

Page 120 Why not include WRF-CMAQ in Figure 2/descussion for comparison (as in Figure 4)?

» We added a paragraph at the beginning of secton 3 (P8, L29-39) and explained the reasons for focusing our analysis and discussion on Asian outflow on WRF-Chem and MOZART results:

“Here, we examine the importance of both synoptic and fine scale venting processes in controlling the total budget of Asian emissions exported to the free troposphere as represented in WRF-Chem, WRF-CMAQ and MOZART. Chemistry is dynamically solved online in WRF-Chem without any interpolations of the meteorological fields, while both CMAQ and MOZART are driven with temporally

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interpolated meteorological fields (1-h to 12-min for CMAQ and 6-h to 20-min for MOZART). Therefore, we focus our analysis and discussion of Asian outflow on WRF-Chem and MOZART results (Figures 2, 3, 4, and 6) to highlight the role of model temporal and spatial resolutions. Figure 5 and supplementary Figure S4 show WRF-CMAQ results analogous to those of WRF-Chem, and we also discussed the difference between between the two regional models. "

»As shown in Figure 5, the vertical distribution of CO for the 7-March frontal outflow episode is very similar between WRF-Chem and WRF-CMAQ, both extending to the upper troposphere (6-9 km), suggesting that the fundamental difference between the regional and global models is larger than the difference between two regional models. We also added a supplementary figure (Figure S4) showing the vertical distribution of CO along the TRACE-P flight track on March 7, which demonstrates the ability of WRF-CMAQ to capture the location of frontal plume as WRF-Chem although the magnitude of CO mixing ratios is relatively lower. This is discussed in the manuscript (P10, L12-20):

"Both WRF-Chem and WRF-CMAQ show strong CO updrafts near Chongqing extending to the upper troposphere, suggesting that some vertical lifting processes are missing in the MOZART model. Mixing ratios of CO are slightly weaker in WRF-CMAQ than WRF-Chem. While differences in isoprene emissions could contribute to the discrepancy, the isoprene emissions are larger in WRF-CMAQ (Figure S2) so the excess CO in WRF-Chem is not due to CO produced during isoprene oxidation. We suspect that the temporal resolution of convective processes, solved every three minutes in WRF-Chem as compared to the interpolation from a 1-h to 12-min time structure in CMAQ, will play a role. "

The pattern for PAN is remarkable similar to CO even though PAN is not a primary pollutant. Page 120 line 22, Figure S3 Again, CO and PAN are very similar. Do you add any new information by showing PAN on top of CO?

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» Indeed, the similar patterns in CO and PAN suggest that the major differences between the models are driven by transport. This point is now added to the text (P9, L13-16). We also consider PAN as an indicator for the potential impacts on ozone enhancements of long-range transport.

Page 122 Figure 5 Refer also to Figure 3, showing the geographical (lat lon) position of the flight track.

» The flight track in both figures (now Figure 4 and Figure 6) is labeled with UTC times, corresponding to the geographical location of the flight track shown in Figure 4. To clarify, we have added the text below to the captions:

"Figure 4: The thick black line labeled with UTC denotes the flight track of the NASA DC8 along which the chemical distributions are illustrated in Figure 6".

"Figure 6: The black line denotes the flight path shown in Figure 4 with corresponding UTC labels"

Page 125 - 127 Discussion on export uncertainty: I do agree that finer scale (regional) models is the main reason for the improved simulation of tracer vertical transport, but... In the companion HTAP publications the import (export) sensitivity of pollutants between the continents vary significantly between the models, and as stated on Page 124, line 14 - 15 the MOZART model is slightly lower than the ensemble mean. This should be better reflected in the discussion on uncertainty. Could some of the discussion in this section be moved to the introduction?

» We agree that there is a significant variation among the models in simulating pollution import and export, and have added the discussion from other HTAP global models (see response to overall comments). We have substantially revised the discussion on export uncertainty in section 3, including the results from other regional (e.g., STEM) and global models (e.g., GEOS-Chem) (P12, L38-46, and P13, L1-20).

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» The following sentences have been moved to the first paragraph of introduction (P2, L27-32):

"Convective systems encompass small-scale fair weather cumuli, active thunderstorms, and meso-scale convective systems [Cotton et al., 1995]. The corresponding lifetime of these systems increases with their size from minutes to about half a day. Therefore, the representation of convective transport and associated clouds and precipitation processes need to be parameterized in the numerical models and is typically sensitive to both the model's spatial and temporal resolution."

Page 131 132 Time evolution ..... The lifetime of CO should be long compared to the residence time of air in the regional model(s)? It is surprising then that CO levels at Mt. Hua and Mt. Happo seems to be lower throughout the column in the regional model(s) all the time?

» It should be noted that CO shown in Figure 8 of the previous version of the manuscript is for the European enhancement only, and not for the total base case level. We have moved the CO temporal evolution associated with European emissions to supplementary figure S6, which shows that the European enhancemnt on tropospheric CO at Mt. Hua and Mt. Happo is very similar among the three models. The minor difference in the upper troposphere may be caused by inconsistencies in winds, mixing, and chemical schemes (VOC emissions and OH abundance etc.) between the global and regional models at the regional boundary, where information is exchanged between MOZART and the regional models.

Figure S5 There is no NO2, middle panel as stated in the figure caption.

» Corrected.

HTAP companion papers included in reference list: TF HTAP (2007), Fiore et al. (2009), Reidmiller et al. (2009), Sanderson et al. (2008), Casper-Anenberg et al.

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(2009). Adittional HTAP companion papers that should be cited:

Citation: Shindell, D. T., Chin, M., Dentener, F., Doherty, R. M., Faluvegi, G., Fiore, A. M., Hess, P., Koch, D. M., MacKenzie, I. A., Sanderson, M. G., Schultz, M. G., Schulz, M., Stevenson, D. S., Teich, H., Textor, C., Wild, O., Bergmann, D. J., Bey, I., Bian, H., Cuvelier, C., Duncan, B. N., Folberth, G., Horowitz, L. W., Jonson, J., Kaminski, J. W., Marmer, E., Park, R., Pringle, K. J., Schroeder, S., Szopa, S., Takemura, T., Zeng, G., Keating, T. J., and Zuber, A.: A multi-model assessment of pollution transport to the Arctic, Atmos. Chem. Phys., 8, 5353-5372, 2008.

Citation: Jonson, J. E., Stohl, A., Fiore, A. M., Hess, P., Szopa, S., Wild, O., Zeng, G., Dentener, F. J., Lupu, A., Schultz, M. G., Duncan, B. N., Sudo, K., Wind, P., Schulz, M., Marmer, E., Cuvelier, C., Keating, T., Zuber, A., Valdebenito, A., Dorokhov, V., De Backer, H., Davies, J., Chen, G. H., Johnson, B., and Tarasick, D. W.: A multi-model analysis of vertical ozone profiles, Atmos. Chem. Phys. Discuss., 9, 26095-26142, 2009.

» **The above papers are now cited in the manuscript.**

Interactive comment on Atmos. Chem. Phys. Discuss., 10, 109, 2010.