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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Investigation of downscaling techniques for the linkage of global and regional air quality modeling" *by* Y. F. Lam and J. S. Fu

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Blue color indicates the change being made in response to the comments. Highlighted texts show the comments for the reviver.

Overall scientific findings: (1) Good findings have been reported with thorough referencing and description of methodology. (2) Although there seems to be minor rooms of elaboration in some sections, overall tightness of the thought progression was good.

Rooms of further clarification and elaboration: (A) Since GOES-CHEM has been ungraded with major features since version 4.0, this qualification of the model should be clear and upfront. It may be worthwhile even mention this version qualification in the

"Introductory" section. For the diligent reader, a correct reference to the features of this older version maybe given.

Response: GEOS-Chem global chemistry model output is one of the most popular global models for generating BCs for the CMAQ regional model. (Tesche et al., 2006; Morris et al., 2005; Streets et al., 2007; Tagaris et al., 2007; Eder and Yu, 2006) Many studies demonstrated that GEO-Chem is capable of capturing the effects from intercontinental transport of air pollutants and increasing background concentrations. (Heald et al., 2006; Liang et al., 2007; Park et al., 2003) Please note the above referenced studies may have used different versions of GEOS-Chem. For example, Heald have used version 4.33 of GEOS-Chem, where as Liang et al. and Park et al. have used version 7.02. GEOS-Chem is a hybrid (stratospheric and tropospheric) 3-D global chemical transport model with coupled aerosol-oxidant chemistry (Park et al., 2006) It uses 3-hour assimilated meteorological data such as winds, convective mass fluxes, mixed layer depths, temperature, clouds, precipitation, and surface properties from the NASA Goddard Earth Observing System (GEOS-3 or GEOS-4) to simulate atmospheric transports and chemical balances. In this study, all GEOS-Chem simulations were carried out with 2o latitude by 2.5o longitude (2o $\times$ 2.5o) horizontal resolution on 48 sigma vertical layers. The lowest model levels are centered at approximately 10, 50, 100, 200, 400, 600, 900, 1200, and 1700 m above the surface. A full-year simulation was conducted for year 2002, which were initialized on September 1, 2001 and continued for 16 months. The first four months were used to achieve proper initialization, and the following 12 months were the actual simulation results. All simulations were conducted using version 7.02 with GEOS-3 meteorological input. Detailed discussion of GEOS-Chem of version 7.02 is available elsewhere. (Park et al., 2004)

NOTE: all the references have been checked. The only one that has different versions of GEOS-Chem as our study is "Heald et al." Additional comment has been added to body of the text.

Please see the revised manuscript page 4 line 27-44 and page 5 line 1-4.

(B)A reference to Mathur on the subject of over estimation of surface O3 concentration is a compounded effect of over detrainment of stratospheric ozone and inadequate representation of free tropospheric mixing and coarse vertical resolution of the CMAQ model used in their study. This is a scientific area needs more elaboration as why deep convection often poses challenge to the modeler.

Response: The quality of BCs depends on the vertical, horizontal and temporal resolutions of global CTM outputs. The latitudinal location and seasonal effects are also playing an important role, which defines the tropopause height that influences the vertical interpolation process between global and regional models. (Bethan et al., 1996; Stohl et al., 2003) In the MICS-Asia project, high ozone concentrations have been observed in BCs from the stratosphere during vertical interpolation process, as the regional model's layers reach above or beyond the tropopause height. (Fu et al., 2008) These high values of ozone induced abnormality to the regional CTM simulation, as regional CTM is only designed for tropospheric application. Tang et al. (2008) studied various CTM lateral BCs from MOZART-NCAR, MOZART-GFDL and RAQMS. They observed that CTM BCs have induced high concentration of ozone in the upper troposphere in CMAQ, this high ozone aloft quickly have mixed down to the surface and resulting an overestimation of surface ozone. Mathur et al. suggested that the overestimation of O3 might also be partially contributed by the inadequate representation of free tropospheric mixing due to the selection of a coarse vertical resolution. (Mathur et al., 2008; Tang et al., 2008) Since the rate of vertical transport of flux is highly sensitive to temperature and moisture induced buoyancies, correct representing deep convection or flux entrainment at the unstable layer in the meteorological model becomes critical to modeling ozone vertical mixing. It should be noted that the single PBL scheme in the meteorological model is not sufficient to simulate correct vertical layer structure on the broad aspect of environmental conditions (i.e. terrain elevation and PBL height) in existing domain. As a result, it introduces uncertainties and errors to the process of determining vertical transport of O3 in air quality model. (Zangl et al., 2008; Perez et al., 2006)

Please see the revised manuscript page 2 line 28-38.

(C) In Fig. 1 and its subsequent reference of the ozone-sondes, the elevated site of Boulder clearly represents a peculiarity of its own distinguish itself from the other two profiles illustrated. Maybe Table-mountain, CA or another mountain site needs to be illustrated in addition to Boulder to give an analysis of the elevated sondes – they have characteristics of their own.

Response: It is a very good idea to study further on the elevated sites to see any special peculiarity can be accomplished. In 2002, only 3 public ozonesonde sites are available. This is why we present them as a starting point to develop the downscaling methodology.

(D)It is obvious that CTM has limitations. However, it can be informative to a diligent reader to get a glimpse of what the authors meant by "detailed surface flux condition" on page 3.

Response: The height of tropopause affects both the stratosphere-troposphere exchange (STE) as well as the transport of O3 at upper troposphere. (Holton et al., 1995; Stohl et al., 2003) In global CTM, well-defined vertical profiles of troposphere, tropopause and stratosphere are established for simulating STE, upper tropospheric advection and other atmospheric processes. Collins (2003) estimated that the net O3 flux from stratosphere could contribute 10 to 15 ppbv of the overall tropospheric ozone. (Collins et al., 2003) Moreover, the transport of O3 is found much higher in upper troposphere than at lower troposphere, which relates to the long lifetime of O3 and the high advective wind in upper troposphere. The advantage of employing CTM outputs as BCs gives a better representation of upper troposphere and the effect of STE can be taken into account. Although global CTM is capable of simulating tropospheric condition, the temporal and spatial resolutions may not sufficient to represent the daily and monthly variability of surface condition since profile of monthly chemical budget is used. Several researchers have demonstrated the outputs of global CTM can be used

in the area of surface background conditions and trends. (Park et al., 2006; Fiore et al., 2003) However, it also revived that the global CTM is inadequate to predict the peak magnitude of O3 at the surface since it is not intended to describe detailed surface flux condition at a high temporal and spatial resolutions. Therefore, the regional air quality model is remained indispensable for simulating the surface O3 conditions.

Please see the revised manuscript page 3 line 40-46 and page 4 line 1-2.

(E)There are quite a few references to the schematics of the "newly developed" downscaling methodology. It is nicer to have it in a flow-chart form – giving details on climatology input,. . ., etc.

Response: We add the flowchart as Fig. 3. in the figure file. Please see the attached figure file.

(F) Abstract was well written except the concluding statements should be stronger and more specific in terms of problem areas resolved.

Response: Recent year, downscaling global atmospheric model outputs (GCTM) for the USEPA Community Multiscale Air Quality (CMAQ) Initial (IC) and Boundary Conditions (BC) have become practical because of the rapid growth of computational technologies that allow global simulations can be completed within a reasonable time. The traditional method of generating IC/BC by profile data has lost its advocators due to the weakness of the limited horizontal and vertical variations found on the gridded boundary layers. Theoretically, high quality GCTM IC/BC should yield a better result in CMAQ. However, several researchers have found that the outputs from GCTM IC/BC do not necessary better than profile IC/BC due to the excessive transport of O3 aloft in GCTM IC/BC. In this paper, we are in effort to investigate the effects of using profile IC/BC and global atmospheric model data, in addition, suggesting a novel approach to resolve the existing issue in the downscaling. In the study, we utilize the GEOS-Chem model outputs to generate time-varied and layer-varied IC/BC for year 2002 with our newly development of tropopause determining algorithm. Comparison

of the new tropopause approach and profile IC/BC approach is performed to demonstrate improvement of adding tropopause in the downscaling process. It is observed that without tropopause in the downscaling process, it creates unrealistic O3 concentrations in IC/BC at the upper boundary conditions for regional tropospheric model. This phenomenon has caused over-prediction of surface O3 in CMAQ. And it is greatly affected by temperature and latitudinal location of the study domain. With the implementation of our algorithm, we have successfully resolved the incompatibility issues in the vertical layer structure between global and regions chemistry models to yield better surface O3 predictions than profile IC/BC on both summer and winter conditions. At the same time, it improved the vertical O3 distribution of CMAQ outputs. It is strongly recommended that this tropopause algorithm should be incorporated into any two-ways coupled global and regional models, where tropospheric regional model is used, to solve the vertical incompatibility existing between global and regional models.

Please see the revised manuscript page 1 line 17-37.

Please also note the Supplement to this comment.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 16011, 2009.

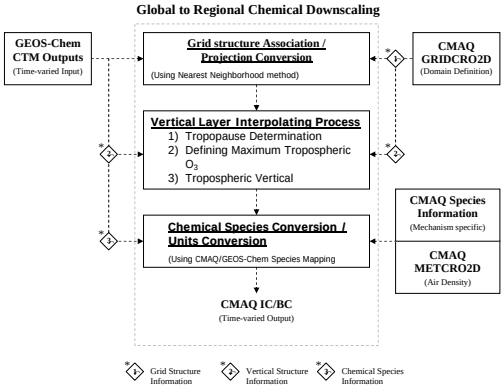

Fig. 3. Systematic flowchart of global to regional chemical downscaling

Fig. 1.