Response to the Third Peer Review of the CMAQ Model

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This response is intended to provide clarifications and additional information to supplement the Third Peer Review of the Community Multiscale Air Quality (CMAQ) Model, conducted for the Community Modeling and Analysis System Center (CMAS) at Research Triangle Park, NC, during December 18-20, 2006. CMAQ is a product of the ongoing collaboration between the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) through the Atmospheric Modeling Division (AMD). The Division greatly thanks the reviewers for their thorough, thoughtful, and constructive review and recommendations. The review provides valuable perspectives of the air quality modeling community needed in setting priorities and directions for the continuing development of the CMAQ modeling system. Responses are organized along the lines of the structure of the Peer Review document, beginning with Section 4 ("Panel's Response to Charge Questions").

4. PANEL'S RESPONSE TO CHARGE QUESTIONS.

Charge Question 2: *What are the strengths and weaknesses of the science being used within the components of the CMAQ development program?*

p. 9 – *"… it is important that a CMAQ-WRF interface be further developed … It is also hoped that progress is made towards incorporating surface nudging capability in addition to the basic nudging …"*

The CMAQ-WRF interfaces are high priority and a very active area for internal development. A one-way interface with the Advanced Research WRF (WRF-ARW) via the Meteorology-Chemistry Interface Processor (MCIP) has been available in the community release of CMAQ since September 2005. MCIP will continue to be refined and updated to remain current with WRF-ARW releases. A one-way interface with the Nonhydrostatic Mesoscale Model of WRF (WRF-NMM) via the Preprocessor to CMAQ (PREMAQ) has been used in the operational air quality forecasting system at the National Centers for Environmental Prediction (NCEP) since WRF-NMM replaced the Eta Model as NCEP's North American Mesoscale (NAM) Model in June 2006. The one-way interface of WRF-NMM and CMAQ will also be refined and updated with an emphasis on closer coupling of the horizontal and vertical grids by making extensive modifications to PREMAQ and CMAQ to support the hybrid sigma-pressure vertical coordinate, the rotated latitude-longitude grid, and the Arakawa E grid staggering that are used in WRF-

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NMM. A two-way CMAQ-WRF (ARW) interface is being developed, and a prototype is expected in late 2008.

We continue to work closely with researchers at Penn State and the National Center for Atmospheric Research (NCAR) and contribute to the development of the surface nudging in WRF-ARW as needed. We are working to make the surface analyses of 2-m temperature and 2-m humidity available in the WRF model for use in the indirect soil moisture nudging scheme in the Pleim-Xiu Land-Surface Model (PX LSM). We plan to collaborate with Penn State and NCAR to add the 10-m winds and implement the surface four-dimensional data assimilation (FDDA).

p. 9 – "*It is also important that the air quality community expedite the implementation of essential WRF features for air quality forecasting applications.*"
We would like the WRF model to have all of the physics and FDDA capabilities that we have been using in the Fifth-Generation Mesoscale Model (MM5) for air quality applications. For physics, we are adding the Asymmetric Convective Model version 2 (ACM2) planetary boundary layer (PBL) model and the PX LSM. This work is nearly complete for the ARW version that we use for retrospective simulations. For air quality forecasting, NCEP runs the WRF-NMM which is then used to drive CMAQ. While it would probably be fairly easy to make our added physics work in the NMM version, it is NCEP's decision on which physics to use for their NAM simulations.

p. 9 - *"AMD may wish to consider assimilating the GOES cloud fields directly into the meteorological model by nudging the cloud liquid water. Otherwise one might have the inconsistency of having clear sky radiation at the surface but vertical mixing and aqueous chemistry by convective clouds."*
p. 15 – *"AMD should consider directly assimilating the GOES cloud fields into MM5 by nudging the cloud liquid water field."*
Clearly, it would be preferable to have all cloud-related parameters consistently nudged toward the GOES cloud fields. However, simply nudging the cloud liquid water field would not necessarily improve the simulation, particularly for convective clouds where the model would not have the dynamic and thermodynamic environment needed to support and maintain convective activity. Thus, "nudged-in" cloud liquid water would probably quickly dissipate and evaporate. Note that our collaborators at University of Alabama-Huntsville are working on techniques to modify the dynamical field to nudge the model towards development of convective clouds in accordance with the GOES cloud fields. As for the noted inconsistencies, such inconsistencies between the cloud effects on radiation and photolysis, as well as those between aqueous chemistry and convective transport, already exist. While "correction" of the radiative cloud effects according to GOES observations may increase these inconsistencies, the benefit will hopefully more than offset the inconsistency problems. We will certainly assess these issues once the GOES assimilation system is operational.

p. 9 – *"It is also desirable that the CMAQ-MM5 interface still be available even after the full transition to WRF has been achieved."*
There are no plans to discontinue support for the CMAQ-MM5 interface using MM5 Version 3-formatted data, which has been NCAR's standard for MM5 since 1999. MM5 Version 2 (which

has not been further developed by NCAR since 1999) has been declared obsolete in the CMAQ system, and its support will be discontinued in the next release of CMAQ.

p. 10 – "*We believe that the ACM2 parameterization will be seen as a major, step-function improvement in vertical mixing for CMAQ. Further testing of the ACM2 scheme should include more comparisons to measured PBL depths. Predicted ozone profiles could also be compared to ozone lidar profile data.*"
Testing and evaluation of the ACM2 PBL scheme in MM5, WRF, and CMAQ is continuing. The next step is to simulate the summer of 2006 at 12 km with MM5 using the PX LSM and ACM2 and CMAQv4.6 (which uses the ACM2 as the default option). During this period there was an extraordinary number of ozonesondes that we can use for comparison to model predictions of potential temperature, humidity mixing ratio, and ozone mixing ratio. There are also PBL heights derived from radar wind profilers made for the 2006 Texas Air Quality Study (TexAQS2006) field study. We will also look into any other data sources for vertical profiles of meteorology and chemistry, such as lidar, Aircraft Communication Addressing and Reporting System (ACARS), and Measurement of Ozone by Airbus In-service Aircraft (MOSAIC), as well as aircraft measurements from TexAQS2006.

p. 11 – *"Addition of the RACM2 chemical mechanism within CMAQ"*
We have had plans for several years to incorporate the Regional Atmospheric Chemistry Mechanism (RACM) into CMAQ. Now, with the release of the RACM2, we agree it is the right time to include it in the next public release of CMAQ, and will pursue this.

p. 11 – *"Inclusion of a surface heterogeneous HONO source to improve model performance"*
We agree with the reviewers on the importance of this issue and are already working to incorporate heterogeneous reactions producing HONO into CMAQ. We plan to incorporate such reactions into the next publicly released version of the CMAQ model.

p. 11 – *"Combine gas and aqueous phase chemistry modules"*
We have recently added aqueous chemistry expertise to our staff. Several improvements are planned for the aqueous-phase chemistry module. We are testing a secondary organic aerosol (SOA) production pathway in cloud water based on laboratory experiments. We will continue adapting a generalized chemical solver (Rosenbrock solver) for the aqueous chemistry; this will allow greater flexibility in the model for testing different aqueous-phase reactions/mechanisms (we also want to add an optional, detailed reference mechanism). Once the generalized solver work is complete, we will begin tests to combine both gas- and aqueous-phase chemistries in one solver.

p. 11 – *"Implement source apportionment for PM trace elements"*
We will continue with our plans to implement the source apportionment of particulate matter (PM) trace elements in CMAQ.

p. 11 – *"AMD … may need to wait for further development of the (nitrogen chemistry) science."*
Nitrogen chemistry is a high priority research area for us. We have recently formed an ad hoc Nitrogen Action Team within the CMAQ group to investigate available data and literature to evaluate and refine the various model processes that transform nitrogen oxide into nitric acid.

p. 11 – *"SOA formation … improvements should include production of SOA from biogenics and aromatics … The panel notes that many of the current problems are due to gaps in fundamental knowledge so this will slow progress."*
The current version of CMAQ includes production of SOA from biogenics (monoterpenes), aromatics (toluene, xylene, and cresol), and alkanes. A major update to the SOA module is underway and slated for the next public release. Explicit mechanisms that are currently available for the oxidation of SOA precursors are incomplete and fairly speculative. Thus, module development is being guided primarily by the results of chamber experiments and field campaigns conducted by the academic community and EPA. A revised SOA module is being derived empirically from these results, and will include SOA production from biogenics (monoterpenes, isoprene, and sesquiterpenes) and aromatics (toluene and xylene). The potential for in-cloud formation of SOA (via glyoxal and methylglyoxal dissolution) is also being explored.

p. 11 – *"Mechanism Performance Evaluation …what is also needed is the quantification of the impact on pollutant predictions and response to precursor reductions. What would be the advantages and disadvantages of using different mechanisms?"*
The issue of differing sensitivities of mechanisms to emission reductions is of great importance to EPA from a regulatory standpoint, and we agree this is of high priority. We recently finished a comprehensive set of simulations with six different control scenarios, winter and summer, for three different mechanisms and are in the process of analyzing it in collaboration with EPA/OAQPS. It is encouraging that, in general, all three mechanisms have similar sensitivities, but we note that there are significant differences in a few areas of the country, a finding we plan to explore in more detail.

p. 11 – *" Several detailed chemical mechanisms exist for the formation of SOA from reactive biogenic species …"*
Given resource limitations for model development, we are relying on members of the academic community to pursue this line of research and we are tracking their progress closely. Researchers at the University of New Hampshire have developed a condensed form of the Master Chemical Mechanism (Griffin et al., 2002) and detailed mechanisms for biogenic oxidation (Chen et al., 2006), and have implemented this in CMAQ for SOA simulations. Recent studies suggest that the more detailed mechanism results in summertime organic carbon (OC) underpredictions comparable to those obtained from the simplified two-product model in CMAQ v4.6 (Chen et al., 2006). We will continue to track any progress made along this very important line of research.

Citation: Griffin, R. J., D. Dabdub, and J. H. Seinfeld, Secondary organic aerosol, 1, Atmospheric chemical mechanism for production of molecular constituents, *J. Geophys. Res.*, *107*(D17), 4332, doi:10.1029/2001JD000541, 2002.
Citation: Chen, J., H. Mao, R. W. Talbot, and R. J. Griffin (2006), Application of the CACM and MPMPO modules using the CMAQ model for the eastern United States, *J. Geophys. Res.*, *111*, D23S25, doi:10.1029/2006JD007603.

p. 12 – *" Cloud Chemistry and Physics … the committee … encourages conducting the suggested research to improve the estimation of pollutant removal from scavenging and wet deposition in CMAQ."*
We will continue collaboration with the WRF-Chem developers to incorporate the Grell convective cloud parameterization into CMAQ. We have completed an initial CMAQ

implementation of the cloud module, and have resolved most of the mass conservation issues. We are currently testing CMAQ's aqueous-phase chemistry and wet deposition modules within the cloud module.

p. 12 – *"Aromatic Chemistry … There is still great uncertainty in current chemical mechanisms' treatment of aromatic chemistry."*
We concur with the reviewers' opinion that a parameterized mechanism is the only feasible way to incorporate improved characterization of important aromatic chemistry in the near term. This has been an area of uncertainty for a long time, and discussions at the recent International Conference on Atmospheric Chemical Mechanisms indicates that we have little better alternative at this time. While the Carbon Bond 2005 (CB05) mechanism does not have improved aromatic reactions, the new 2007 Statewide Air Pollution Research Center (SAPRC07) mechanism and RACM2 both do, and we are planning to incorporate both into CMAQ.

p. 12 – *"Dry Deposition … while the resistance approach is a commonly used approach in air quality models, its accuracy has not been fully evaluated because of the lack of field data. Significant uncertainty may be introduced to model estimations due to uncertainties in the dry deposition algorithm … a study should be conducted to assess the overall uncertainty introduced to model forecasts due to uncertainty in the dry deposition …"*
The dry deposition model in CMAQ (m3dry) is under continuous development. While our current emphasis is on a new bidirectional surface flux capability for ammonia and mercury, we also periodically review and refine the parameterizations and parameters in the scheme. Note that a key element of m3dry is its use of the bulk stomatal conductance and aerodynamic conductance directly from the LSM in the meteorology model. Thus, the stomatal pathway is predetermined and probably the least uncertain of the components. For most chemical species the surface resistances, for both wet and dry surfaces, are the most uncertain parameters. These parameters could be the focus of a sensitivity study to determine the range of effects on CMAQ model outputs of a reasonable range of surface resistance values.

p. 13 – *"HAP Chemistry – greater attention should be paid to photochemical reaction products of HAPs and their potential impact on human health. These reactions or intermediate species are currently not included in current chemical mechanisms."*
We are intrigued by recent work from the University of North Carolina's One Atmosphere chamber that indicates that photochemical reaction products of hazardous air pollutants (HAPs) and non-HAPs can contribute significantly to adverse effects in human cell cultures. Developing chemical mechanisms to describe this is not in our current near-term plans, but we would like to pursue it to help EPA understand the toxicity of PM. We realize this would be quite a challenge because we have not yet determined the specific toxic compounds that are producing these effects, nor is the current state of knowledge sufficient to determine their reaction yields or rate constants. Because of its importance, we will keep it under consideration for future improvements to CMAQ for HAPs.

p. 13 – *"Fine Scale Modeling and Exposure – Model Limits … The decision to continue in this direction needs to be weighed with other research priorities. What are the limits of this approach and what are the uncertainties? What types of exposure and pollutants are the targets of this application?"*

Implementing ambient air quality standards is a well understood and established application of the CMAQ modeling system. “Fine-Scale Modeling and Exposure,” however, addresses two emerging high-priority areas of interest identified by EPA: (1) the linkage of modeled ambient air concentrations to human exposure assessments, and (2) air quality model simulations of multipollutant “hot spots” in urban areas. As EPA continues to adopt a source-to-exposure-to-effects risk paradigm, the ability to link emissions, ambient concentrations, and human exposures will become more critical in fully assessing the impact of air pollutants and air pollution reduction strategies on human health. The “Fine-Scale Modeling and Exposure” research area also involves the creation of hybrid modeling tools to examine residual nonattainment issues, especially for fine particulates in urban areas. The limits of using deterministic models at these scales will be explored. EPA’s program office has stated that having modeling tools to address this issue is important for future State Implementation Plans (SIPs). These priorities are documented in EPA’s air research program multiyear plan. A balance between traditional and emerging research areas needs to be considered.

Charge Question 3: *What is the quality and relevance of the model applications and evaluations being conducted as part of the CMAQ Modeling Program?*

p. 4 – *“… the current approach to uncertainty evaluation is unclear, and more efforts should be devoted to dynamic evaluation”*
p. 13 – *“ greater efforts are needed for dynamic and diagnostic evaluation. A thorough internal review of AMD’s model evaluation efforts may be warranted to clearly define the objectives and goals and ensure that the approaches are appropriate and sufficient for meeting those goals.”*
The CMAQ “ensemble” project, which was referred to by the review committee as uncertainty evaluation, is first intended to consider a range of CMAQ predictions in a regulatory context. A typical CMAQ evaluation involves one simulation where choices are made when setting up the meteorology, emissions, and air quality model for this evaluation. When evaluating the results, how much of the model performance is reflective of CMAQ regardless of options chosen, and how much would it change if you made different choices? Therefore, when using the term “ensemble,” we are referring to a CMAQ ensemble reflective of a reasonable collection of simulations from a particular model version with different “good” choices. In the long term, we hope that this effort will also help to develop a reasonable series of CMAQ simulations to characterize a realistic estimate of uncertainty in CMAQ predictions. However, as stated in the presentation, we are at the early stages where we are first assessing the impact of meteorological influences. The next stage will be to include variations introduced by other sources of uncertainty (e.g., emissions, additional chemical mechanisms, modifications to key processes). We appreciate the committee’s encouragement to expand the suite of simulations as planned. We anticipate that it will further our insights into how critical these choices are when developing a CMAQ simulation.

Diagnostic evaluation is actually approximately one-third or more of the evaluation effort ongoing in the Division; however, it was not presented in the CMAQ peer review this year because it was highlighted in the previous CMAQ peer review. The evaluation presentations at the December 2006 peer review were intended to introduce new areas of model evaluation that are being explored in the program, not to present the full evaluation program. Currently, the most effort is invested in diagnostic and dynamic evaluation. As the committee also commented, less effort will now be required for operational evaluation with less frequent model releases. Also, the “CMAQ ensemble” effort that was discussed at length above is a relatively small investment of time at this stage since it is exploratory. It was included in the peer review to share new ideas/efforts with the committee. In summary, the priorities and emphasis suggested by the peer review committee are quite consistent with the current balance of effort in the evaluation program.

p. 13 – “ … *to take full advantage of this capability, the user community will benefit from any simplification in the installation process of the AMET software system, given the various dependencies that must be preinstalled.”*
Tests with a small group of beta users have identified some installation issues and software requirement issues that need to be worked out before the Atmospheric Model Evaluation Tool (AMET) can be publicly released. We are working to resolve, or at least minimize, the installation issues of the current version of AMET. In particular, we are working with CMAS to generate an automated installation script (configure) that most UNIX-based software can use. Once these installation issues are satisfactorily addressed and a minimal amount of instructional documentation is developed, we plan to make the current version of AMET available for public distribution.

p. 14 – *“It is desirable that AMET's functionality will be expanded to also include non-standard data sources including satellite derived fields. AMET should be adapted to also cater to ensemble based modeling. Furthermore, there should be avenues to incorporate user developed analysis tools into AMET.”*
AMET currently works with air quality data from surface networks measuring speciated $PM_{2.5}$ concentrations, precipitation chemistry from the National Atmospheric Deposition Program (NADP) and Mercury Deposition Network (MDN), and ozone concentrations from EPA's Air Quality System (AQS) sites. While introducing other surface networks is feasible, bringing satellite data into AMET is not. Based on our experience working with several different satellite data sets without AMET, it is clear that we do not have the resources to develop software tools that “operationalize” satellite data processing and pairing with model output. Since AMET relies primarily on R codes, it would be straightforward to modify codes to include multiple simulations (e.g., ensembles). However, the first hurdle will be to develop a more user-friendly installation process (as mentioned above) before we can decide how much community involvement in further AMET advancements can be maintained.

p. 14 – “ …*it is also desirable that in house evaluations within AMD emphasize statistically rigorous techniques while performing intercomparisons. Sensitivity results should be accompanied by tests of significance of the patterns of anomalies or correlation. … metrics linking sensitivity of the air quality forecasts to the uncertainties in the meteorological inputs should also be developed.”*
We agree that this is needed, and are working on these issues. As noted above, the full model evaluation program was not presented at the peer review. Methods are currently being tested to assess how statistically significant the differences are between two model simulations (e.g., two versions of CMAQ, or a series of varied simulations with different inputs or model specifications). Additionally, analyses are underway to look at the impact of meteorological uncertainties on the air quality predictions.

p. 14 – “*Greater attention to model evaluation and analysis … we recommend a workshop of experts to develop improved evaluation methods. The goal is to eventually communicate CMAQ strengths and shortcomings to the community and clearly define the limits of the model’s capabilities.*”
The Division is planning to host a small workshop of experts in August 2007 to discuss, deliberate, and build consensus recommendations.

p.14 – “*We also recommend formal model comparisons using a wide range of available models and chemical mechanisms.*”
We agree that an extensive model comparison would be valuable. The presentation on CMAQ ensembles is a beginning stage of comparisons in which we are looking at the sensitivity to different meteorology, different chemical mechanisms, and eventually other model specifics (e.g., chemical reaction rates). Efforts are also underway to develop simulations with the Comprehensive Air Quality Model with extensions (CAMx) to include in the dynamic evaluation study of the NO_x SIP Call, along with CMAQ simulations using both the Carbon Bond version 4 (CB4) and SAPRC mechanisms. A broader, more extensive comparison with other air quality models would require a coordinated effort across many modeling groups. AMD does not have resources to initiate a formal model intercomparison of this type. Perhaps this is something that the EPA Science to Achieve Results (STAR) program would consider sponsoring.

p. 14 – “*Analysis should utilize high time resolution data for ozone, other species, and meteorological variables. Continue to work with ozonesondes and other vertical data. Evaluations should emphasize the use of process analysis type comparisons.*”
While presentations at the peer review did primarily present the regulatory ozone metric of the maximum 8-hour average of ozone, the evaluation group routinely looks at diurnal patterns in ozone and hourly meteorology. The encouragement to include these analyses in presentation of results is noted and considered for future presentations. It is probably worth noting that diurnal analyses of ozone were highlighted in the evaluation of the previous CMAQ v4.5 when changes in the minimum K_z were made to address nighttime issues with ozone modeling. Since diurnal performance in ozone did not change substantially between CMAQ v4.5 and v4.6, it was not emphasized this year. Process analysis (PA) is used in some evaluation studies in the Division, such as the NO_x SIP Call dynamic evaluation study, where a manuscript focused on the PA results is under development.

p. 14 – “*Model response analysis … Intensify evaluation of CMAQ response to changes in emissions and meteorology… dynamic evaluation of the CMAQ model, examining how well it captures pollutant responsiveness to emissions changes, is crucial. Unfortunately, dynamic evaluation is both more difficult to conduct than operational evaluation, since responsiveness cannot be directly evaluated against observations, and it appears to have received short shrift relative to the other forms… More should be done to pursue the NOx SIP Call research in greater depth, especially since the initial findings suggest that CMAQ may be underpredicting ozone responsiveness to NOx emissions and/or meteorology.*”
We agree that this is a high-priority area of evaluation research for AMD. As previously mentioned, a series of CAMx simulations is also being developed for the NO_x SIP Call study, so that we can assess the responsiveness of both models with consistent inputs. A manuscript is

being drafted for the NO_x SIP Call study to present these results in the peer-reviewed literature. Additionally, process analysis from these simulations is being analyzed and written up as a paper as well.

p. 14 – *"EPA should also identify other opportunities …for conducting dynamic evaluation of CMAQ, including cases that go beyond the NOx-ozone relationship to also consider particulate matter or mercury."*
While not presented at the peer review because the research is in early stages, AMD is developing a baseline characterization of air quality and emissions for tracking of the Clean Air Interstate Rule (CAIR). These efforts are intended to begin the next stage of dynamic evaluation for the upcoming NO_x and SO_2 emissions changes planned in 2009 and 2010 as part of CAIR and the Clean Air Mercury Rule (CAMR).

p.14 – *"Dynamic evaluation should be linked where possible with diagnostic evaluation to examine why responsiveness is either over-predicted or under-predicted."*
We agree that the coordination between dynamic and diagnostic evaluation is critical to identifying the cause(s) of biases, which could lead to model improvements. As part of the NO_x SIP Call project, there are ongoing parallel analyses to assess meteorological and chemical drivers for the ozone changes predicted in the NO_x SIP Call case. During the coming year, we plan to gain a more process-level understanding of those drivers.

p. 15- *"Protocol for model performance evaluation … What is missing in the current guidance is a protocol for a rigorous process based performance evaluation of these models… AMD should play a key role in developing a protocol that emphasizes model performance evaluations based on whether the model achieved the right pollutant concentrations for the right reasons."*
The expert workshop on model evaluation that is planned for August 2007 will offer an opportunity to make progress toward model evaluation guidance. However, EPA/OAQPS has the official responsibility for providing guidance to the States for model evaluation. It is hoped that the results from the AMD-sponsored model evaluation workshop will provide complementary recommendations to OAQPS guidance to consider the diagnostic approach suggested above.

Charge Question 4: *What are your perceptions of the integration across different elements of the CMAQ Modeling Program (links between model development, applications, evaluation)? What is your perception of the usefulness of the CMAQ Modeling Program to the EPA, states, other customer needs and research community?*

p. 15 - *"For example it is important to interface with field programs. AMD should help frame research questions from a CMAQ perspective."*
We agree with the assessment that the CMAQ forecast applications place AMD in a unique position to identify shortcomings of the modeling system. In fact, since its initial deployment in forecast mode, continuous analysis of the CMAQ forecast predictions have helped to identify several issues related to long-term air quality modeling (e.g., role of cloud mixing, photolysis attenuation due to clouds, role of lateral boundary conditions, seasonal biases in PM predictions, and performance issues in specific regions such as California's Central Valley). Several of these aspects are now areas of active research and development within AMD, and have been communicated to the research community through presentations at technical conferences and

workshops. Through use of the forecast model for providing in-field guidance during field studies, AMD is also taking an active role in such studies and is collaborating with other Divisions (NOAA/ESRL) and agencies (NASA) involved with the design of field experiments. It is our hope that these activities will lead to a more active role in framing research questions and defining measurement needs from a modeling perspective.

p. 15 – *"We encourage CMAQ and CMAS to set up a more formal survey of the users and stakeholders to identify their needs and concerns. They need to perform a formal exercise of identifying what are the main issues, what can best be addressed and what will affect the users most positively."*
CMAS conducts outreach using multiple outlets that encourage users and stakeholders to provide feedback on their modeling needs and concerns. The CMAS website, annual CMAS conferences, *CMAS Quarterly* newsletters, trainings and workshops, and other electronic outlets provide opportunities for the CMAS user community to interact with CMAS and comment on their needs. Through a survey form on the CMAS website, information is collected about the modeling community. The survey asks website users to provide details about how they are using the models, the types of educational opportunities that interest them, and any comments that they have regarding the models and/or services supported by CMAS. The website also provides a suggestion box that acts as a catch-all for all comments submitted. Surveys are administered at the annual CMAS conferences, and provide information about how to contact the CMAS Center through quarterly newsletters e-mailed to the community. Regular model training and customized workshops are held where CMAS administers surveys to assess how the needs of the community can be better met. Other CMAS resources that the modeling community can use to provide feedback about their modeling needs include the m3list, m3user, and emregional listservs, the CMAS Help Desk, and the CMAS administrative email, cmas@unc.edu.

In the air quality forecasting program with NOAA, we have established a formal Focus Group composed of stakeholders using the daily CMAQ model predictions as guidance for local air quality forecasts. Feedback is received throughout the forecast season, as well as at an annual Focus Group Workshop, as to how useful the model guidance is, and how any systematic model biases had affected the stakeholders' use of the model results for their area. This feedback is quite useful in planning future modifications or new research to improve the modeling system.

p. 15 – *"The time between CMAQ releases should be lengthened, perhaps to 18 to 24 months."*
We agree with this recommendation, and have changed our planning such that the next CMAQ model release will occur in 2008. We anticipate that this change in schedule will allow the CMAQ modeling team to focus more on documenting their research and model improvements/ evaluations in the interim between releases.

Charge Question 5: *Are there modeling research areas that are not being addressed or are given insufficient attention with the CMAQ Modeling Program? Are there current areas of research emphasis that might be given lower priority or eliminated? For the resources available to the CMAQ Modeling Program, are they being used in an effective manner in terms of the choice and quality of research being conducted?*

p. 16 – *"Numerics were not greatly addressed during this review. The panel suggests that this is one area that should be addressed over the next 1.5 years."*
The numerical algorithms in the CMAQ model were covered in depth during the first CMAQ peer review in 2003. We agree that this is a continuing area of interest, especially with regard to the tensions between accuracy and efficiency in the modeling system. We will consider updating the panel at the next peer review on any subsequent improvements or modifications to the numerical routines, including parallelization methods, made since the last reporting on this topic.

p. 16 – *"Related to two-way coupling, efforts should address as to whether the present CMAQ mass-conservation scheme is adequate …it will be also of interest to explore avenues of coupling WRF and CMAQ where the structure may be more modular …"*
Tracer transport calculations require higher-order schemes (compared to those used in dynamic models) to resolve the sharp gradients in pollutant distributions, especially in the vicinity of source regions. To satisfy the discrete continuity equation in the chemistry-transport model, either winds or density fields from the meteorological model need to be adjusted to maintain mass-consistency. Even if the dynamics and chemistry-transport models use the same grid and time steps, a mass-conservative field satisfying the finite-difference form used in the meteorological model may not yield conservative tracer advection in the chemistry model if it uses a different advection scheme. Thus, only if the same numerical scheme and discretization are used for solving continuity equations for air density and tracer mass can on-line coupling provide advantages for mass conservation. Consequently, we believe that the current mass-conservative advection based on rediagnosis of the vertical velocity field in CMAQ will be adequate for both off-line and on-line modeling.

The use of the Earth System Modeling Framework (ESMF) in coupling WRF and CMAQ in an on-line fashion is very much in our developmental plans for the integrated modeling system. However, given that ESMF currently does not offer the requisite flexibility to facilitate the modular and consistent coupling needed for such a system, our initial approach is based on calling CMAQ as a subroutine from WRF. The approach requires minimal changes to the CMAQ model (only at the driver-program level) to be used in off-line and on-line modes; a similar approach has been demonstrated to work effectively with a predecessor version of CMAQ and MM5 by collaborators at UNC's Carolina Environmental Program. However, as capabilities within the ESMF evolve, transitioning the on-line system to be ESMF compliant will be pursued.

p. 17 – *"We believe reforecasting is something AMD should consider in the mid-term future (2-3 years out) for its real-time AQ forecasts."*
AMD is already investigating a number of approaches to "combine" forecast results with near-real-time measurements to assist in improving the forecast skill. Two bias adjustment techniques for O_3 and PM predictions have been investigated: (1) a simple "hybrid method" that continuously combines model forecast changes in concentrations with current observations, and (2) a more mathematically rigorous approach based on the Kalman filter. The applicability of the two approaches in improving short-term air quality forecast skill is being investigated by examining a variety of performance metrics and practical considerations associated with current air quality forecast usage. A manuscript summarizing the findings from this investigation is under preparation.

p. 17 – *"… and it would seem beneficial for the AMD air quality forecasting to be carried out in collaboration with these groups."*
We are aware of the activities of several ensemble research programs within the air quality community and are collaborating with these groups. For example, we are participating in the ensemble forecasting project underway at University of Maryland.

p. 17 – *"The panel did not see sufficient evidence that EPA has developed a thorough strategy for examining model uncertainty or a plan for how this examination will inform other model development and evaluation efforts. The ensemble modeling conducted to date captures only a very narrow range of possible model set-ups (choices of MM5 set-up and chemical mechanism) and thus does not represent the full range of uncertainty in CMAQ…. any uncertainty analysis should identify uncertain parameters or other input choices most engendering uncertainty in responsiveness, not just concentrations."*
As stated in our earlier responses to this point, the current results presented to the committee are interim results where only the meteorology inputs were varied. We recognized that this is a narrow range of possible model setups. Additional simulations are underway as originally planned to introduce uncertainty from emissions and chemistry.

We disagree with the statement above that the approach may not inform other model development and evaluation efforts. The current results have identified some key issues related to meteorology that already have informed model development efforts. Additionally, having a range of meteorology inputs can also help to identify issues that are likely driven by chemistry-related or emissions-related uncertainties. As we explore the impacts from emissions and chemistry for this study, we anticipate learning a great deal more that will inform model development and evaluation.