UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
National Exposure Research Laboratory
Research Triangle Park, NC 27711

March 31, 2010

OFFICE OF
RESEARCH AND DEVELOPMENT

MEMORANDUM

SUBJECT: Atmospheric Modeling & Analysis Division Peer Review

FROM: Dr. S.T. Rao
Director (E243-02)
Atmospheric Modeling & Analysis Division

TO: Dr. Lawrence W. Reiter
Director (D305-01)

As you are aware, the Division peer review was conducted during January 27-29, 2009 by a panel of experts representing academia, government, and industry. The review was quite complimentary of Division's research and our national and international leadership in the air quality modeling and analysis field. However, the panel made several recommendations for further improving the quality of research being conducted by the Division and building a strong air quality modeling research program.

We have carefully considered the Panel's recommendations and attempted to respond to them. The attached report provides the Division's initial response and its action plan to address the major comments of the peer review panel. If you feel that we have adequately responded to the review report, please forward it to the Chair of the Panel. We are prepared to address any additional comments the Panel might have after they reviewed our response.

I would like to take this opportunity to thank you for organizing the Division peer review and your continued support to the Division.

Attachment

cc: Dr. Linda Sheldon
Dr. William Benson
Dr. Robert Dyer
Ms. Jewel Morris
Ms. Lee Riddick

Response to the Peer Review of the
Atmospheric Modeling and Analysis Division

March 29, 2010

The National Exposure Research Laboratory (NERL) conducted a peer review of its Atmospheric Modeling and Analysis Division (AMAD), with the goals of assessing the quality of the scientific research being performed within the Division and the responsiveness of the Division in addressing the needs of the U.S. Environmental Protection Agency (EPA). A review panel, consisting of individuals representing academia, industry, and government with expertise in air quality modeling research and science management, met with the Division staff and management in Research Triangle Park, North Carolina during January 27 through January 29, 2009. This report provides the Division's initial response and its action plan to address the major recommendations of the Peer Review Panel. (Details of the peer review materials along with the complete Report of the Peer Review Panel, dated February 2009, are available on the Division's website: http://www.epa.gov/amad/.)

Before responding to the recommendations of the Peer Review Panel, it is worth noting the Panel's key findings on "the most significant accomplishments of the Division":

- The Division has established the Community Multiscale Air Quality (CMAQ) model as a leading state-of-the-science regional air quality modeling system, with a large user community.
- The Division has delivered timely and relevant modeling products to EPA and its broader user community.
- The Division has, on its own initiative, developed an independent and on-going external review mechanism for the CMAQ modeling system, and has developed a rigorous internal model evaluation program.
- The Division has developed a balanced portfolio of core research and applied activities in support of EPA needs.
- The Division has established continuing and substantive interactions with the Office of Air Quality Planning and Standards (OAQPS) and other Agency clients and partners.
- The Division has established an effective outreach mechanism to serve the broader user community.
- The Division has aggressively addressed the issue of staff renewal.

The above positive findings provided the foundation for the Peer Review Panel to make specific recommendations to further improve research in the Division. The Panel provided a synthesis of their findings and recommendations for the Division. The Panel's overarching recommendations and our responses are given below. The reviewers stressed that the Division's research plans should be made public so that the CMAQ user community can identify complementary initiatives and minimize duplicative research. Other review recommendations identified the need to plan research based on themes and functional teams involving multi-pollutants and media including climate change. In response to these reviewer recommendations, AMAD has developed research white papers, detailing AMAD's strategic research plan for three key research initiative areas that encompass AMAD's scientific expertise as well as identifying areas where external collaboration is sought. These initiative areas are:

- Climate and Energy Research
- Air Quality Model Connection to Human Exposure and Health
- Making the Air Quality Ecosystem Connection

Figure 1 illustrates the linkages and interactions among these research areas as well as Division's core research to maintain the CMAQ model at the cutting edge of science.

AMAD will make these plans publically available through the Community Modeling and Analysis System (CMAS) center and AMAD websites. These plans will be reviewed and updated as necessary on an annual basis.

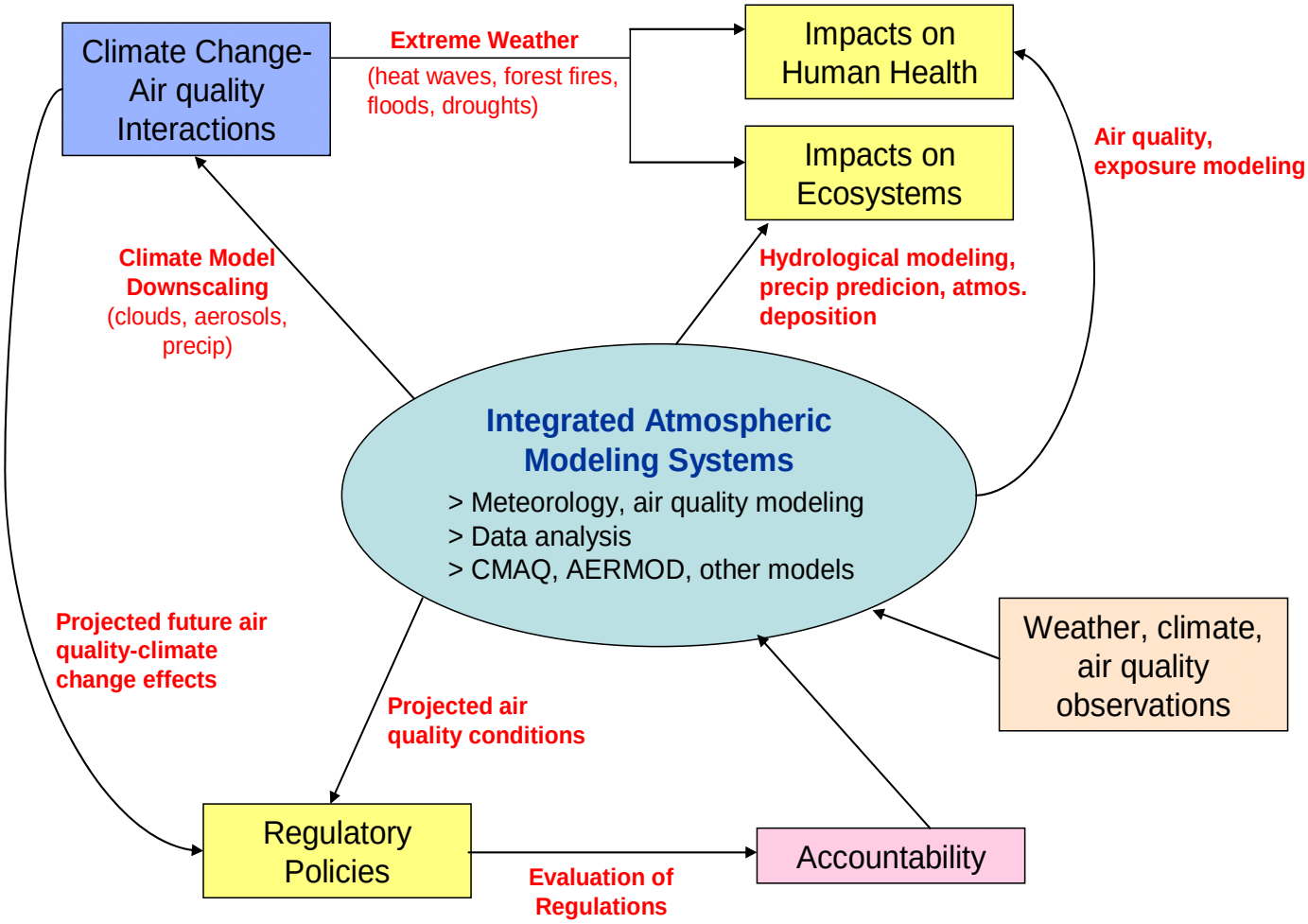

Figure 1. Modeling interactions among air quality, climate change, ecosystem health, and human health.

Recommendation: Preserve the Division's existing resources for regional air quality modeling while responding to new Agency initiatives.

Response: Each year we review and prioritize our research activities with NERL management and stake holders to ensure that we are addressing the most important and critical Agency needs. Most recently, Lisa Jackson and Dr. Paul Anastas, the EPA Administrator and ORD Assistant Administrator, respectively, have articulated the seven highest priorities and greatest challenges for EPA. The top three of these priorities are: 1) Taking Action on Climate Change, 2) Improving Air Quality, and 3) Assuring the Safety of Chemicals. AMAD takes a significant role in research programs within each of these Agency priority areas, while helping advance exposure science and its applications consistent with NERL's Exposure Framework.

Expanding the Division's focus to include fine-scale and global-scale modeling applications will be made in a manner to minimize any erosion of our core capabilities in maintaining the CMAQ model at the cutting edge of science for regional-scale applications. We will continue to emphasize development and evaluation of the CMAQ model system on regional-to-continental scales. The coverage of the expanded scales is actually a natural and continuing evolution of our work at the regional scale as we have been extending capability in recent years to improve coverage of both temporal and spatial scales. This expansion of scales is directed by current Agency priorities, including regional-level environmental impacts of global climate change, and the exposure of humans and ecosystems to environmental contaminants. The Panel has suggested that we form new partnerships to accomplish the work on expansion of scales. In fact, we have been actively partnering with NASA (GISS), NOAA (GFDL),

DOE (both PNNL and ORNL), and NCAR to establish the regional modeling linkage to global scales. For fine-scale modeling and linkage with local exposures, we are collaborating with grantees from Emory University, the University of Michigan, and the University of Washington on exposure studies, our sister Division (HEASD), as well as NYS Department of Health and CDC on linkage of atmospheric modeling to epidemiological and health studies. In this way, we can continue to maintain our focus on regional-scale modeling while addressing the Agency's top priorities in climate change and exposure to chemicals in the environment.

The Panel has also recommended that we add additional staff to accomplish the new work. While we seek additional resources to support these endeavors and will continue to utilize EPA, NRC, and ORISE post-docs, students, and visiting scientists to augment existing staff, it must also be recognized that existing resources may have to be utilized to cover this work, necessitating some adjustments to current priorities and capabilities. We have taken advantage of short- and long-term training opportunities for AMAD staff to further their professional development in the emerging research areas, and will continue to seek these opportunities. Our expansion of scales to encompass hemispheric-to-global modeling for climate change applications is in early stages, and has relied on resources beyond the Division's base budget, through internal ORD proposals and ad-hoc funding. Continued expansion of the Division's global program will rely on future funding of such proposals or an increase in the Division's base funding to cover this program area.

Recommendation: Develop a public strategic plan, with a 3-5 year time horizon, for the continued development, evaluation and support of the CMAQ model system.

Response: We will plan to formalize and document our strategic plan and publicize it through our website and the Community Modeling and Analysis System (CMAS) Conference. We will have this strategic plan included in the periodic peer review of CMAQ modeling activities. Initially, we prepared "White Papers" on AMAD's STRATEGIC RESEARCH PLANS for:

- CLIMATE AND ENERGY RESEARCH,
- AIR QUALITY MODEL CONNECTION TO HUMAN EXPOSURE AND HEALTH, and
- MAKING THE AIR QUALITY ECOSYSTEM CONNECTION

We have solicited external reviews of these plans to ensure that we are doing the right science in the right manner, consistent with the resources allocated to the Division. In addition, we will have a series of Retreats in early 2010, including a meeting of AMAD management and PIs with their counterparts in EPA/OAQPS to better understand client needs over the next several years based on anticipated regulatory drivers. AMAD will then convene an internal Retreat to scope out a Division five-year Strategic Research Plan, encompassing both the core areas of regional air quality model system development and evaluation, as well as major application areas such as those described in the White Papers. We anticipate posting a copy of the resulting Strategic Plan on the AMAD website for distribution to the public. We are planning to present and discuss the Division research strategy at the 2010 CMAS workshop so the participants will have an opportunity to provide their recommendations.

In preparing for the AMAD Division Retreat, we have considered a structured process to prepare for and develop the Strategic Plan (see Appendix A). The process includes interviews with key stakeholders and staff regarding their needs and research priorities, Agency and Laboratory priorities and drivers, and a synthesis of this information in advance of the Division Retreat. In addition, we are developing a set of principles to help guide our decisions on research priorities. A draft of this set of principles is given in Appendix B. In addition to external drivers beyond the Division, we consider the likelihood of a given research program or direction to substantially improve the Division's modeling capabilities for multiple applications, including human and ecosystems exposure research and air quality management. This determination is made through sensitivity and uncertainty analyses with our models, and through lessons learned in our model evaluation program as well as periodic workshops with the scientific community. For example, the CMAQ model's systematic underestimates of organic aerosol have led to a research emphasis on secondary organic aerosol processes as well as on evaluation and improvement of some of the primary carbonaceous aerosol emissions. This research has already produced improvements in the seasonal distribution of CMAQ's organic aerosol estimates, and by extension, of the PM2.5 estimates.

Our resource split between core research and applications is roughly 50% / 50%, and we intend to maintain this approximate division as we move forward into new areas. Pictured in Figure 2 below are some major anticipated milestones for AMAD research over the next five years, subject to change based on the discussions at the Retreats mentioned above as well as with NERL management.

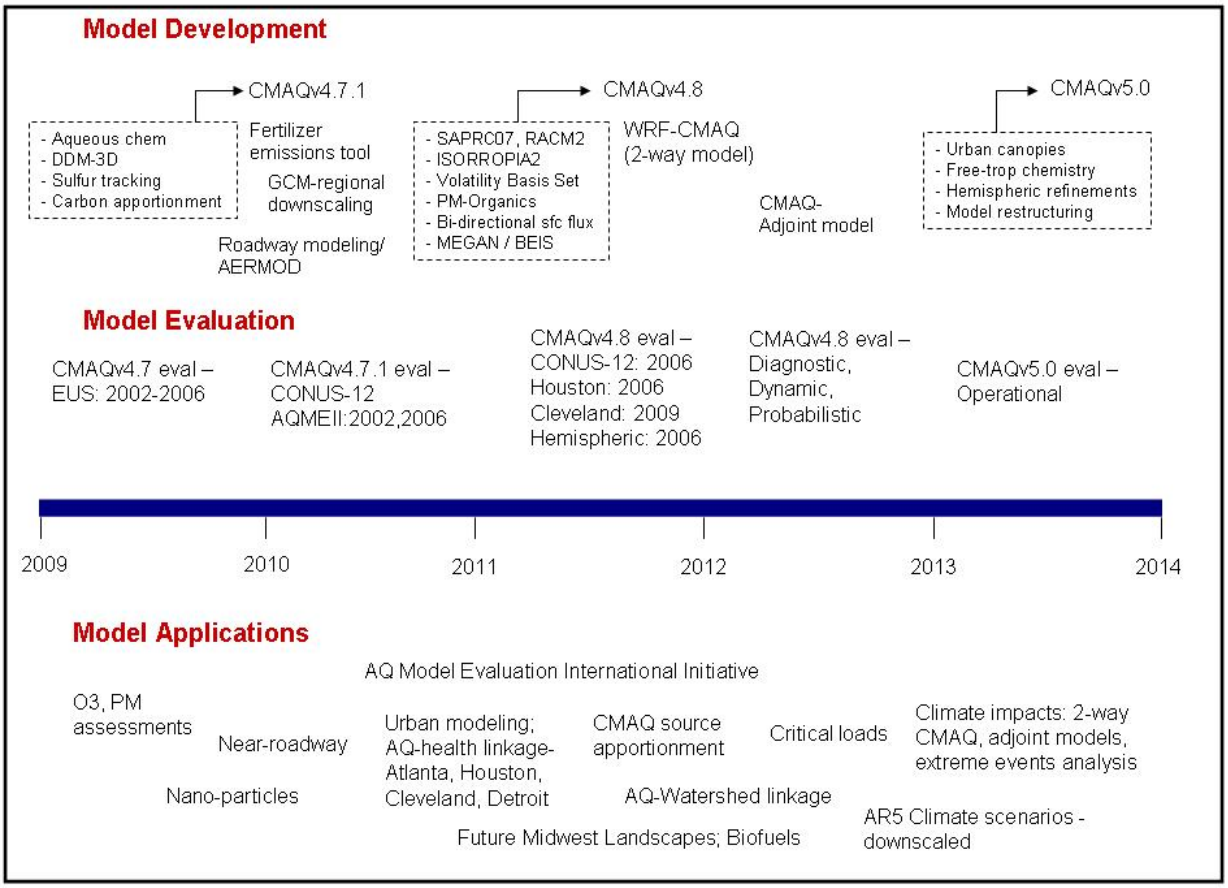

Figure 2. Highlights from preliminary plans for AMAD model development, evaluation, and applications, 2009-2014.

Recommendation: Define, as transparently as possible, pathways for users to contribute to the CMAQ modeling system.

Response: We have been encouraging contributions and extensions to the CMAQ model from the larger modeling community. Once our strategic research plans and White Papers have been made available for the community, they will provide guidance as to the highest priorities for model improvements. We will seek partnerships with those groups wishing to fund and conduct research to advance these highest modeling priorities. The CMAS Center was established to not only provide user support but also as a possible resource for external developers to work with internal CMAQ developers via CMAS to incorporate and test their algorithms and modules within the overall modeling system. While AMAD and other EPA offices have provided steady modest funding to support such activities, CMAS would clearly benefit from having additional external support and active commitment from external groups for code development and maintenance. It is not feasible for the AMAD staff alone to maintain any and all community contributions to CMAQ with our existing resources. AMAD acknowledges this concern and will also seek guidance from the CMAS External Advisory Committee to maximize incorporation of user-developed code and tools and to identify effective means to inform the CMAQ model community of the pathways and requirements for contributing to the model system, including any required quality assurance and evaluation steps This action will, however, be contingent on other members of the modeling community to also contribute to funding to CMAS as well as the availability of funds to the Division to expand support to CMAS. We believe that it is not only EPA who has a stake in the further development of the CMAQ model. We will review and evaluate guidance on CMAS to determine if clarification of the process is needed for determining how we make decisions on what is incorporated into the EPA version of the CMAQ Model. We will also continue our strong involvement in NATO/SPS's International Technical Meetings on "Air Pollution Modeling and its Application" as well as in

AQMEII. These meetings provide additional forums for effective interaction with the international community on our activities and opportunities for collaboration.

Recommendation: Make available, as possible, inputs and results for selected CMAQ simulations, which can serve as model application and test platforms for the user community.
Response: We plan to distribute through the CMAS website or EPA web site the inputs and results for selected CMAQ simulations. The results from selected AMAD simulations with CMAQ will be made available through EPA's Remote Sensing Information Gateway (RSIG) which also contains analysis tools for examining observation network, commercial aircraft data, and satellite data for comparison with model results. We are in the process of completing year-long simulations for the Center for Disease Control's (CDC's) Public Health Tracking System. These results for CDC are targeted for the first release of such information.

We also participate in collaborative exercises for model evaluation and intercomparison, such as the North American Mercury Model Intercomparison Study (NAMMIS) and the Air Quality Model Evaluation International Initiative (AQMEII). Model inputs and results are made available through these studies for the purpose of further understanding model behavior and improving process representations in the models (give AQMEII web site).

Recommendation: Seek focused, expert input on Division methodologies, tools and models at critical steps in their development.
Response: We plan to utilize the periodic peer reviews of CMAQ modeling activities as well as conferences and workshops to obtain input to our developmental activities. AMAD has received very useful input from Peer Review Panels conducted for the CMAQ model system in 2003, 2005 and 2006, and during the Division review in 2009. We plan to continue these Division- and Laboratory-based reviews to provide guidance on our modeling research plans. We will continue to utilize the annual CMAS Conference for interaction with the user community on our plans and developments. Further, we have engaged external peer reviewers to provide input on selected "white papers" or task descriptions on critical research plans and key developmental products. In addition, AMAD scientists have played a pivotal role in the development and implementation of the Air Quality Model Evaluation International Initiative (AQMEII). In this initiative, U.S. and Canadian modelers will join their counterparts across Europe in several year-long model simulations of each continent for model intercomparison and evaluations. Also, we approached the private sector to fund participation by the private sector in the AQMEII activity. The work included here will contain important and innovative approaches to advancing the science in air quality modeling and its applications (refer to AQMEII web site here). This activity, in conjunction with the Division's leadership and involvement with the NATO forum on air pollution modeling, will be critical mechanisms to soliciting international feedback on our activities.

The next planned release date of an updated version of the CMAQ modeling system is September 2011. We plan to engage the next CMAQ peer review panel in early 2011 to assess the science upgrades and the model evaluation plans for this new version of CMAQ. In addition, the release of the Division Strategic Plan later in 2010 will allow the wider modeling community to provide feedback on our research plans. We hope to engage the community in discussion of our Strategic Plan at the next CMAS conference in October 2010.

Recommendation: Continue a formal working relationship with air quality forecasting operations.
Response: We do plan to maintain a working relationship on air quality forecasting with our colleagues in NOAA and EPA's Office of Air Quality Planning and Standards (OAQPS). We are planning periodic scientist-to-scientist workshops to ensure that developments and findings of all parties are shared and that all parties continue to benefit from each other's experiences. However, it should be noted that this relationship does not include the daily interactions with NOAA as occurred in the first five years of the program since NOAA has decided to take over the responsibility for air quality forecasting research and support for operational aspects. In light of the changes in the roles and responsibilities and decisions made by NOAA, AMAD will not be engaged in daily interactions with NOAA; the AMAD personnel involved in those operations have been assigned to our new initiatives.

Summary of Action Items/Timeline

A. Near-term:

i. Formalize and document AMAD Strategic Plan and publicize it through Division website and the Community Modeling and Analysis System (CMAS) Conference.

– September 2010

ii. Communicate "White Papers" on AMAD STRATEGIC RESEARCH PLANS for Climate and Energy Research, Air Quality Model Connection to Human Exposure and Health, and Making the Air Quality Ecosystem Connection through Division website; These plans were externally reviewed during March 3-4, 2010.

- September 2010

iii. Review and evaluate guidance on CMAS to determine if clarification of the process is needed for determining how we make decisions on what is incorporated and maintained in the EPA version of the CMAQ Model.

- October 2010

iv. Post results of CMAQ model simulations for the Center for Disease Control's (CDC's) Public Health Tracking System for public access.

- on-going

iv. Participate in periodic scientist-to-scientist workshops with NOAA to ensure that developments and findings on air quality forecasting are shared with all parties.

- April 2010 (next teleconference), and workshops (2 times per year) after that

B. Long-term:

i. Division strategic plan included in the periodic peer review of CMAQ modeling activities during FY-2011.

- March 2011

ii. Distribute through EPA and collaborator ftp sites the inputs and results for selected CMAQ simulations.

- on-going

C. On-going:

i. Review and prioritize AMAD activities each year with NERL management and clients to ensure that we are addressing the most important and critical Agency needs.

- November 2010 (FY-2011 Tasks reviewed)

ii. Continue active involvement in NATO/SPS's International Technical Meetings on "Air Pollution Modeling and its Application" and AQMEII to maintain interactions with the scientific community in EU and Canada.

- September 2010 (Next AQMEII Workshop and NATO Conference)

iii. Utilize the periodic peer reviews of CMAQ modeling activities as well as conferences and workshops to obtain input to our developmental activities.

- March 2011 (next CMAQ model peer review)

iv. AMAD scientists will participate in the development, expansion, and implementation of the Air Quality Model Evaluation International Initiative (AQMEII).

- on-going; first model results workshop planned for September 2010 and a follow on workshop in September 2011

v. Utilize EPA, NRC, and ORISE post-docs and students to the maximum extent to enhance our personnel in critical areas, with emphasis on initiative areas.

- on-going

For each of five research theme areas, the panel has identified strengths and weaknesses of AMAD's research programs and made recommendations. These are summarized in the following sections of our response.

1. Research Theme: Model Development and Diagnostic Testing

Limitations*: The Division is in danger of trying to cover too much ground with too few resources, especially in relation to future model development plans to extend the scale of CMAQ to the neighborhood scale and the hemispheric scale. Note that this same concern was raised in 2003 by the 1st CMAQ external peer review panel that was organized by CMAS.*

Response: AMAD recognizes and shares the review assessment that the Division could be in danger of covering too much ground with too few resources. The expansion of the scale of applicability of the CMAQ model to both the urban/finer scales and to the hemispheric scales is motivated by the need to represent in a more robust and consistent manner the scale interactions of atmospheric processes and to provide a comprehensive tool that can assist in

addressing emerging Agency problems. Building appropriate linkages with human exposure and health studies and to address issues related to urban residual non-attainment necessitates the application of the models at scales significantly finer than those employed in traditional regional-scale applications. The motivation for the linkage with the global/hemispheric scale is two-fold: (1) it provides a means for investigation of more robust methods for specification of lateral boundary conditions and simulated background values which would be needed in applications to assess emission controls for compliance with the lower NAAQS, and (2) in conjunction with the development of the coupled WRF-CMAQ modeling system, provides unique opportunities to assess and reduce current uncertainties associated with the spatial heterogeneity in short-term radiative forcing resulting from regional air pollution. The expansion of AMAD's research portfolio in both these directions will leverage activities in the broader user community and aims at complementing rather than "re-inventing" broader external efforts. While we will seek additional resources to support these endeavors, it must be recognized that existing resources may have to be utilized to cover this work, necessitating some changes to current priorities and capabilities. However, we will review and prioritize our activities each year with NERL management and clients to ensure that we are addressing the most important and critical Agency needs. For added clarification on the Division's research planning and prioritization process, we reiterate here the procedures followed by AMAD as discussed with the Panel:

Research Planning Within the EPA/NERL Atmospheric Modeling and Analysis Division

The AMAD research program is guided by Agency priorities as well as by the greatest uncertainties in the science that bear on those priorities from the perspective of an atmospheric modeling program. The research planning process is described below. It involves both strategic components, along the lines of ORD Multi-year Plans (3-5 year time horizon, and sometimes longer) as well as tactical components, including the Task planning process at the Division level (1-3 year time horizon). While program priorities are established at the Agency, ORD, or Laboratory level, details of research projects, approach, methodologies, and deliverables are derived from discussions within the Division. Also discussed below is the structure and outline of AMAD's research within the particular Multi-Year Plans relevant to AMAD.

The research planning process within EPA is generally driven by a "top-down" process. While much of AMAD's direction comes from ORD and NERL guidance, there is ample opportunity for "bottom-up" initiative for translating the ORD's and NERL's broad scientific priority areas into specific scientific questions for AMAD to address, and for devising the research approaches and methods for addressing the questions. AMAD staff scientists and managers participate in the research planning process at all levels, but especially in creating the Division-specific research tasks to pursue and in creating the collaborations outside of AMAD for strengthening the depth of the research approaches.

Figure 3 illustrates the planning process from ORD-level through the Division-level. Note that in recent years the planning process at all levels has undergone some significant process changes, so the figure captures the current planning process as a snapshot in time. Significant guidance comes to NERL and to AMAD through the ORD Multi-Year Planning (MYP) process. The MYPs most influential to AMAD's research include the Clean Air, Ecosystems Protection, and Global Change MYPs. The principal coordinators for creating these plans, the National Program Directors (NPDs), solicit suggestions from internal EPA customers for the research (both within ORD and from EPA's major Program offices, in Research Coordination Teams, RCTs) as well as from outside of EPA, including the academic, private sector, and international communities. RCT membership also includes Assistant Laboratory Directors who gather inputs from Lab management and Principal Investigators for use in the MYP development. Guidance from external advisory bodies, such as EPA's Science Advisory Board, Clean Air Scientific Advisory Committee, Board of Scientific Counselors, and the National Research Council, is also used to help inform the directions in the MYPs. In addition to the high-level input, the NPDs involve senior scientists and managers from across ORD in the discussions and often in the writing of sections of the MYPs. AMAD scientists have participated in the development of the Air, Eco, and Global MYPs. In addition to the on-going planning process through MYPs, ORD also has specific research initiatives of shorter-term duration that may influence research priorities at the Lab and Division level. These initiatives may derive from Congressional direction, or be generated by ORD as future or emerging issues.

In turn, the NERL creates Implementation Plans for planning Lab-specific research suggested by the MYPs. The NERL plans are also informed by the NERL Exposure Framework[1], guiding human health- and ecosystem-related research from the exposure perspective. Teams of scientists from across NERL, including AMAD scientists participate in the discussions and writing of the Implementation Plans. These plans provide significant guidance to AMAD in developing Division Tasks and deliverables to satisfy Annual Performance Goals and Measures, as specified in the MYPs. The AMAD Science Council, composed of the Division Director and Deputy, the Division Science Advisor, and the research theme leads, meets monthly to plan and implement the Division Tasks and allocate resources to priority research areas. Staff scientists are invited to participate in research planning discussions at Science Council to provide PI perspectives in Task and project planning. In addition to the Science Council, Task planning is guided by information deriving from weekly AMAD seminars delivered by staff scientists who provide summaries of their on-going research, and periodic Division retreats where 1-2 days are spent in discussions and brainstorming Division research priorities and directions. In addition to these internal activities, AMAD conducts panel peer reviews of its Community Multiscale Air Quality (CMAQ) modeling program approximately every two years, and NERL conducts periodic Division peer reviews. The CMAQ model peer reviews focus on the model's science and model's use in regulatory and scientific applications. (Reports from recent CMAQ peer reviews can be found at http://www.cmaq-model.org.)

Division research tasks supporting the principal AMAD research themes are developed and updated on an annual basis, covering the current and next two fiscal years (e.g., FY2009-FY2011). The tasks and projects contained in the tasks are written by AMAD PIs and staff scientists. Research task plans are reviewed by AMAD management as well as NERL managers to assure they are responsive to the requirements of the ORD and NERL planning process, as well as to insure the plans are scientifically sound. Major deliverables from the Tasks receive both internal EPA and external peer review.

Examples of priority research areas in AMAD that have evolved from the process described above include an emphasis on the chemical and physical atmospheric processes leading to accurate model simulation of $PM_{2.5}$, a focus on high-resolution modeled spatial estimates of atmospheric pollutant deposition as a function of land-use for ecological assessments, the combined use of regional air quality and local dispersion models for better estimates of local ambient concentrations for human exposures, and the downscaling of global climate model simulations to North American regional scales for assessing climate change impacts on regional and local air quality.

Division resources are allocated to priority research areas, commensurate with the significance of the research area to the Agency mission as determined by NERL management and NPDs, as well as by the size of the challenges represented by the research area, the number and complexity of the anticipated products, and the probability of successful outcomes. We will utilize EPA, NRC, and ORISE post-docs to the maximum extent to enhance our personnel in critical areas, with emphasis on initiative areas. An example of the Division's resource allocation is given in Figure 4 for FY-2008, where the allocation for global climate change research has been increased compared to previous years, given the new Agency emphasis in this area. In any given year, roughly 50% of Division resources are allocated to core program research, and 50% to initiative/application areas. This can vary depending upon the number of funded initiatives within the Division.

[1] A Conceptual Framework for U.S. EPA's National Exposure Research Laboratory, EPA/600/R-09/003 (2009), http://www.epa.gov/nerl/documents/nerl_exposure_framework.pdf

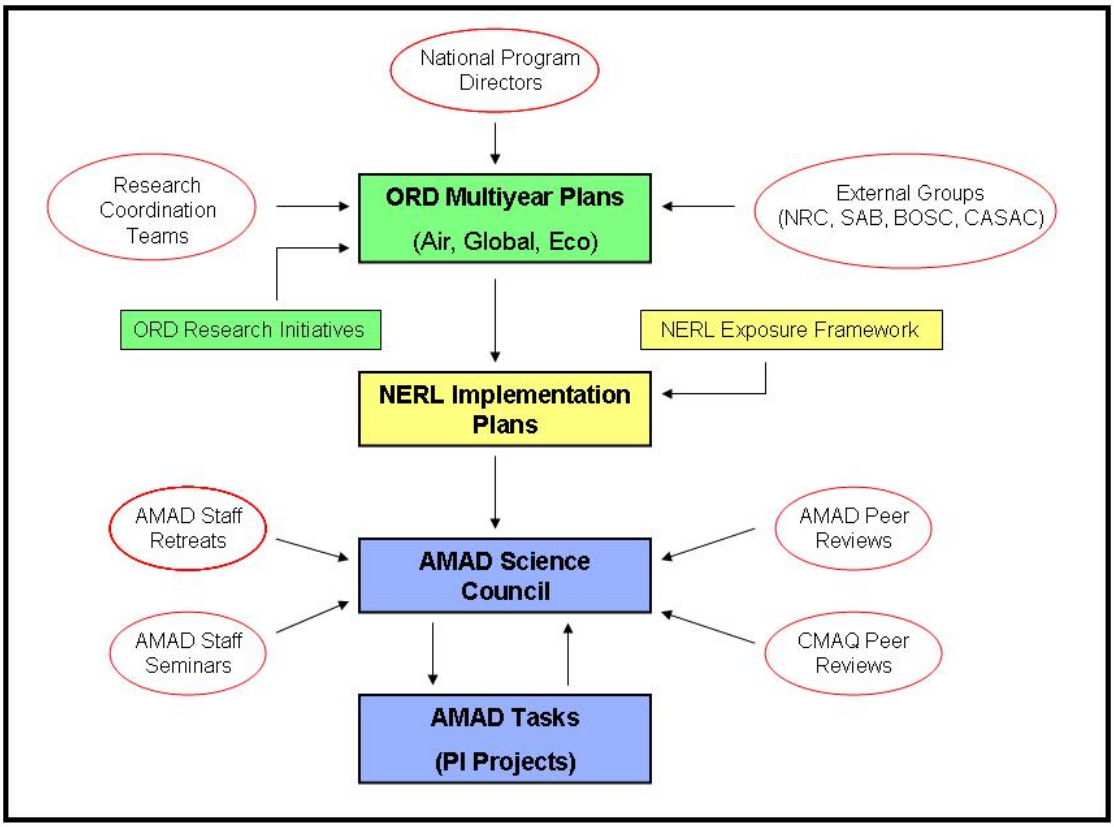

Figure 3. Research planning process informing AMAD research directions

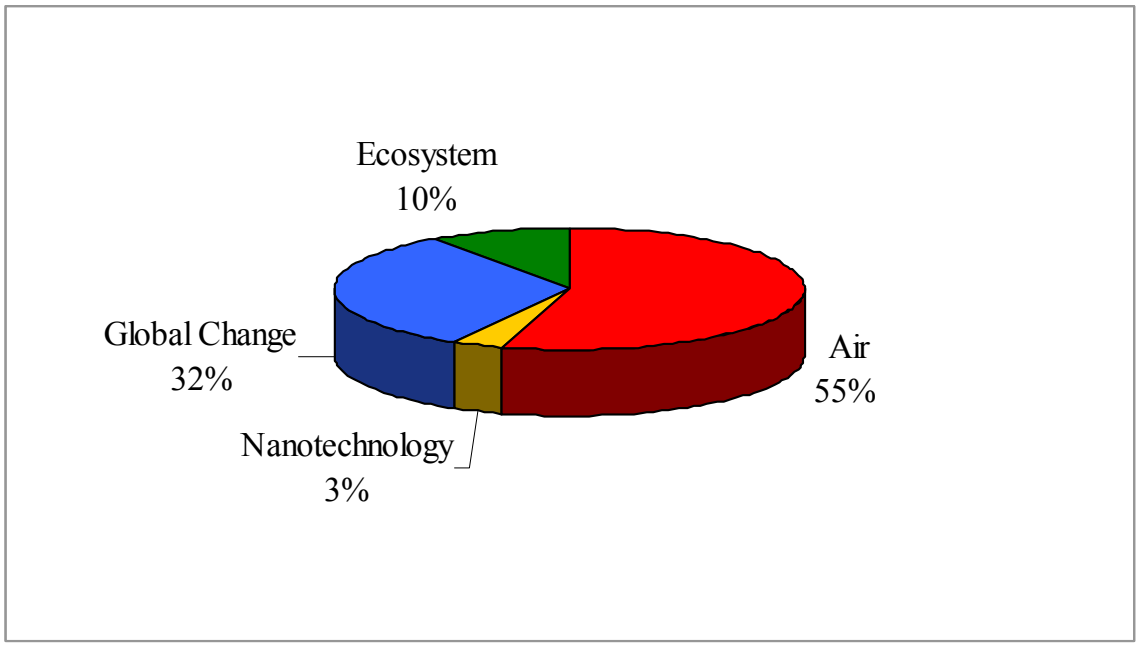

Figure 4. AMAD Extramural Resources and FTEs by MYP in FY-2008 ($3.2M & 47 FTEs)

***Suggestions for Improvement**: There are a few other emerging issues that were not raised by AMAD during the on-site review. The Division might also consider addressing the following issues, with the understanding that the future directions discussed above may take precedence depending upon Agency needs*:
Response: The format of the review precluded detailed presentations and discussions on all aspects of future technical directions. In many cases, we have already initiated efforts along the lines suggested by the reviewers, and we are pleased to hear that these are consistent with the suggestions by the reviewers. We have addressed the specific suggestions of the reviewers in the following responses to their recommendations and suggestions.

***Recommendation:** PM number density and the ultrafine mass fraction. These aspects of PM have been raised by some in the health community as being more closely linked to health impacts, including by studies of near-roadway PM exposure. Modeling these aspects of PM, however, will place new demands on the development of emissions inventories and on the numerical treatment of the PM size distribution in order to conserve both number and mass simultaneously*.
Response: While CMAQ does simulate PM number density and size distributions, the best approach may be to utilize CMAQ along with other models such as AERMOD to address this issue. The "HYBRID" model, which combines the features of CMAQ and AERMOD, is being developed and evaluated. AMAD recognizes that PM size and number distributions are important for assessing optical properties, and, consequently, radiative effects of aerosols and also potentially important in health assessment studies, and where possible, we will compare model results with available measurements from field studies. AMAD is working with scientists in NERL's Human Exposure and Atmospheric Sciences Division and the National Risk Management Research Laboratory on transport of fine particles in the near-roadway environment. The results of this work will help determine the direction of this research to explore the ultrafine number density and mass fraction in the vicinity of roadways.

***Recommendation:** Hemispheric AQ modeling. Moving to this spatial scale requires improvements to both model inputs and the model itself, including the specification of hemispheric emissions (i.e., Asian and European anthropogenic emissions, biogenic emissions), hemispheric meteorological modeling and data assimilation from a wide range of data sources, including satellites, aircraft, buoys, and ships, the treatment of background chemistry and emissions (e.g., DMS, CH4), and the treatment of upper boundary conditions and stratosphere-troposphere exchange*.
Response: In the initial effort, AMAD will leverage global emission data sets already developed for anthropogenic sources outside of the continental U.S. and on-going Division research for the estimation of biogenic emissions. AMAD is already exploring the use of modeled potential vorticity fields to represent the modulation of O_3 due to stratosphere-troposphere exchange and its effects on surface-level O_3 background. Even current applications on annual cycles over continental scales necessitate the need to critically evaluate the ability of current mechanisms to represent background chemistry. AMAD plans to use findings from external research to guide the inclusion of additional long-lived species and chemical pathways as needed.

***Recommendation:** Possibility that semi-volatile VOC emissions from vehicular and other sources are not accounted for in current emission inventories and AQ models. Work by the group at Carnegie-Mellon, for example, suggests that these emissions may be a missing organic PM source*.
Response: AMAD is already collaborating with Carnegie Mellon University on the incorporation of the volatility basis set (VBS) approach into CMAQ. The development of this capability would help in a systematic investigation of the relative roles of emissions and atmospheric pathways regulating ambient organic PM distributions.

***Recommendation:** Data fusion techniques. There have been some efforts to combine AQ model predictions and AQ and other measurements (e.g., precipitation, cloud cover) by various approaches, including kriging, model output statistics, objective analysis, and model-space and observation-space methods in data assimilation, but further improvements and applications of such techniques to CMAQ are likely possible*.
Response: Efforts are underway at AMAD and other NERL divisions to conduct a systematic comparison of a variety of data-fusion techniques of varying complexity and for a variety of pollutants. These efforts are motivated by AMAD's desire to create and provide to the client offices the most accurate air quality surfaces for use in health assessment studies.

***Recommendation:** Development of a 2-way nested domain capability or the use of a non-uniform grid system that would provide higher resolution in specific areas of interest within larger domain simulations. Such a capability is fairly common in meteorological modeling and would be useful for modeling situations where chemical feedbacks*

from a high-resolution domain would have significant impacts on the coarser scale as well. One example might be AQ modeling for mega-cities, where a realistic treatment of small-scale chemistry and dispersion in the urban core and urban plume could conceivably change the predicted regional-scale impacts.
Response: AMAD acknowledges that atmospheric chemical and transport processes, are inherently linked, and the Division recognizes the need for representing the impact of smaller scale processes on larger scale ambient concentration distributions. Unlike meteorological modeling and in cases where passive tracers are simulated, the extension of the traditional "two-way" nesting paradigm for non-linearly evolving chemistry poses considerable conceptual (e.g. mass conservation) and numerical challenges (e.g., discrete boundaries between meshes of different resolutions). AMAD instead is currently investigating (in collaborations with partners at CMAS) the development and application of variable-grid methodology to represent the interactions between fine and coarse resolutions; an early version of the approach was tested in MAQSIP, a modeling system with many attributes similar to CMAQ.

Recommendation: *A more in-depth study of horizontal physical diffusivity and its parameterization for different grid scales is in order. Presently, numerical diffusion is often lumped together with physical diffusion, and the true impact of this lumping is often unknown. What is known though is that the errors would tend to be large near the peak concentration regions and regions with large concentration gradients.*
Response: AMAD agrees with this suggestion and recognizes that the extension to the finer scale in particular would require a more detailed and critical assessment of the role of horizontal diffusion and methods to represent it. Unfortunately, this has not been an area of active investigation even in the external community, as suggested by the dearth of new publications in this area.

Recommendation: *Develop a public strategic plan, with a 3-5 year time horizon, for the continued development, evaluation and support of the CMAQ modeling system. It is clear that the Division has identified a set of future directions and formulated a development plan for CMAQ, but these are not widely known outside of the Division. As the Division's own internal plans for model development and evaluation become more widely known, the broader CMAQ community can identify complementary initiatives and avoid duplicative research.*
Response: See earlier response on p. 3

Recommendation: *Define, as transparently as possible, pathways for users to contribute to the CMAQ modeling system. Presently, the manner in which the Division identifies scientific results that drive model development initiatives is not widely understood. It is also not clear to the broader user community what types of quality assurance and model evaluation criteria need to be met for user-developed tools to be incorporated into the modeling system. Making these processes transparent will promote user engagement and may in turn benefit the Division. In view of AMAD's efforts to encourage the development of an external CMAQ community, it would be worthwhile for AMAD to communicate its position on this subject to the community and to describe the minimum requirements that should be met.*
Response: See earlier response on p. 4

Recommendation: *Establish a process to communicate and consult with the external user community before features are removed from CMAQ and provide a rationale for such removals when a new model version is released. Many new features and improvements have typically been introduced in each CMAQ release, but before version 4.7 was released in Sept. 2008, very few existing features had been removed (the RADM2 gas-phase chemistry mechanism was dropped in version 4.5). When CMAQ version 4.7 was released, however, five CMAQ options were dropped: plume-in-grid (PinG); CB4 gas-phase chemistry mechanism; AERO3 module and AE3 mechanism; RADM cloud module; and the stand-alone mercury version of CMAQ. The loss of support for selected model features means a loss of backward compatibility. It would be helpful to the larger CMAQ user community if advance warning of such decisions were given and an opportunity to comment was made available. It would also be informative as part of the release of a new model version to provide reasons for the removal of any features. For this panel, the loss of support for the CMAQ PinG module in version 4.7 was the most surprising. AMAD's response to the 2nd CMAQ External Peer Review report (p. 4) stated that new research and development on the PinG module was to be phased out after 2005 and a reason was given, but the PinG module was then upgraded in CMAQ version 4.6 before being phased out in version 4.7. Others in the CMAQ user community might have been similarly surprised.*
Response: The rationale for removal of specific modules in new model versions is solely science-based. Specific modules are only dropped from new releases if updated versions (either representing new science, or more accurate numerical solutions, or computational efficient algorithms) are available. The RADM2 and CB4 chemistry

mechanisms, the AERO3 aerosol module, and the RADM convective clouds schemes were all phased-out once updated and alternate modules had been adequately tested and their scientific integrity and advancements adequately demonstrated (e.g., peer review, beta-versions). In all cases, the original module and its anticipated replacement (e.g., the CB4 and CB05 mechanism, the RADM and ACM cloud schemes, AERO3 and AERO4 modules in version 4.6, AERO4 and AERO5 in version 4.7) were made available in the previous released version to facilitate the transition process in the community and the intent to phase-out specific modules was communicated to the user community via the release notes. In most cases, the CMAS polled the user community to check usage of old modules and this feedback is used in arriving at decisions to remove old modules. In spite of CMAQ's modular structure, significant effort is required to ensure that all possible combinations of process options work together. As science in individual modules is updated, and becomes part of the standard model configuration across the user-community, older and seldom used versions are dropped.

In the specific case of the PinG module in CMAQv4.7, the default version of the module was removed, since it was developed for model applications on relatively coarse horizontal grid resolutions, which are not typical in current regional applications. AMAD acknowledges that there has been significant research and development in this particular area in the external community (e.g., CMAQ-APT) and hopes that these evolving modules will fill this particular void. The removal of the default PinG module in version 4.7 should not be interpreted as AMAD's position on the scientific credibility of the overall approach. We should also note that it is important to examine whether the use of PinG would lead to different emission control options.

We agree with the reviewers that to avoid unnecessary confusion, AMAD should explore ways to better communicate development plans and the underlying research philosophy; making the Division Strategic Plans publicly available as suggested earlier would be a step in that direction. Additionally, CMAS is exploring methods to actively engage the CMAQ development community in discussing issues related to model development and collaborations; a Wiki site has been developed to facilitate informal discussions of this nature. We will review and evaluate procedures and communication protocols to determine if additional measures are needed.

Recommendation: *Seek focused, expert input on Division methodologies, tools and models at critical steps in their development. The Division has a strong track record of soliciting frequent external peer reviews of the CMAQ modeling system. These reviews have tended to be comprehensive examinations of the modeling system. These should continue, but the Division should add focused teams that can examine more narrowly defined emerging model system developments (e.g., coupled models and WRF-CMAQ, hemispheric CMAQ, inverse emission modeling, or the Carbon apportionment tool). These focused teams should provide input at project initiation, pre-release, and other key model development stages.*
Response: Typically, past CMAQ peer reviews have focused on specific aspects of the modeling system (e.g., PM modeling, meteorology modeling and coupling with the Chemical Transport Model) and have provided focused reviews of these specific model components. These external reviews will be expanded to also include a review of our research plans and anticipated research tasks for major new development projects and initiatives. We plan to conduct periodic reviews of research into new areas. This will start with external review of our "White Papers" on AMAD STRATEGIC RESEARCH PLANS for:

- CLIMATE AND ENERGY RESEARCH,
- AIR QUALITY MODEL CONNECTION TO HUMAN EXPOSURE AND HEALTH, and
- MAKING THE AIR QUALITY ECOSYSTEM CONNECTION

We will have these plans externally reviewed to ensure that we are doing the right science in the right manner.

Recommendation: *AMAD should continue a formal working relationship with NOAA on operational AQ forecasting. Maintaining such a relationship would benefit both parties. NOAA would continue to have a formal mechanism to access AMAD expertise during the transition to a larger forecast domain that supports AQ forecasts for Alaska and Hawaii and to operational PM2.5 forecasting. This agreement would also institutionalize NOAA's access to the EPA's latest anthropogenic emission inventories, to AMAD's models and methodologies to estimate natural emissions, and to the near-real-time provision of continent-wide O3 and PM2.5 measurements via the EPA's AIRNow meta-network. AMAD in turn would continue to learn from having CMAQ applied 24/7 over a continental-scale domain using a different meteorological driver (WRF-NMM) with advanced meteorological data assimilation techniques to forecast both gas and aerosol species. Such an agreement would also provide EPA with a formal procedure to provide NOAA with newer versions of CMAQ, thus supporting an ongoing transition of research advances to the operational arena and avoiding a divergence of AQ forecasts being made by the EPA for policy*

purposes with those being made by NOAA for short-term guidance. If this specific relationship is successful, formal methods for integrating operational applications with Division research may become a more general practice.

Response; AMAD's transition to EPA in July 2008 and the creation of an air quality modeling group at NOAA's Air Resources Laboratory (ARL) has changed the role and level of participation of AMAD in operational air quality forecasting. NOAA/ARL made a decision to take over AMAD's previous day-to-day responsibilities in this project. AMAD has continued collaborations with NOAA/ARL on developmental tasks related to extensions to Alaska and Hawaii by providing requisite emission processing data. AMAD anticipates continuing a productive working relationship with the NOAA AQ forecasting, and is engaged in discussions identifying areas of collaboration and synergy (e.g., sharing updates to model code, bias-correction of model forecasts and their availability via AIRNOW). Periodic Scientist-to-Scientist Meetings have been proposed to ensure effective communications and collaborations on areas of mutual interest. However, in light of the changes in roles and responsibilities, AMAD will not be engaged in daily interactions with NOAA; the AMAD personnel involved in those operations have been assigned to new initiatives. Nevertheless, with the successful development and transfer of the CMAQ model and processes for daily air quality forecasting, we certainly intend and expect to maintain involvement in the program to ensure effective enhancement and utilization of CMAQ by all parties.

Recommendation: *When required, the Division's core activities should be expanded in order to maintain any Division capabilities that are not currently required to support Agency policy activities but which have been required in the past and are likely to be needed again in the near future. A significant investment is usually required to build the scientific expertise and modeling tools needed to bring leading-edge science to support policy development. In a research environment where science continues to evolve at a rapid pace, both expertise and models must also be updated on an ongoing basis to be of most use. For example, CMAQ mercury modeling has contributed to Agency policy in the recent past and will almost certainly be needed in the future. Efforts should be made by the Division to maintain this capability.*

Response: We agree with the recommendation that both the models and the Division's expertise must continuously evolve, and note that AMAD has strived to build on past Division research and expand its expertise to not only address current Agency issues, but also position itself to anticipate and adequately address emerging issues. The mercury modeling capability in CMAQ continues to evolve; the expansion to the hemispheric scale was in part based on results of the NAMMIS study that clearly demonstrated the importance of lateral boundary conditions on regional mercury modeling.

2. Research Theme: Model Evaluation

Recommendation: *As the Division takes on new areas of activities in climate-change impact on air quality, prioritization of projects becomes necessary. Prioritization ought to be based on the direct practical relevance of the project and its ability to improve understanding and/or to truly reduce uncertainty.*

Response: As discussed earlier, Appendix B outlines our research prioritization criteria, and focuses a strong emphasis on those areas for which the modeling system is most sensitive and which contain the largest uncertainties. Emphasizing research areas in this way will not only reduce those uncertainties, but do so in a way that makes the most impact of the results of the modeling system. In addition, NERL's Exposure Framework establishes a series of filters by which potential research can be judged and prioritized. First, the research must support the mission of the Agency. Second, the research must be deemed as being exposure research and meet at least one of several criteria, including: (1) whether NERL possesses unique expertise, (2) whether there is a need for an integrated approach, (3) whether NERL has sufficient and appropriate expertise and resources, and (4) whether NERL can truly make an impact by performing the research. It is through this prism that the Division's possible extension into other research areas will be judged. Figure 3 outlines our internal research planning process for informing research directions and setting priorities. This process also helps to identify when shifts in emphasis of the research are warranted, such as when a new release of CMAQ encompasses a large body of research. Further, we have organized to facilitate a balance of our research on fundamental science versus new applications. We have about 50% of the staff involved on model development and evaluation issues and about 50% involved in model applications to address current and emerging issues. Through these efforts, we feel comfortable that our research is focused on the areas of highest payoff in model performance, including reduction of uncertainty, and in the most important applications.

Recommendation: *The AMAD is encouraged to work with non-CMAQ model developers to gain from each others' insights and modeling experience.*
Response: While the Division has been a leader in advancing the science and application of model evaluation techniques, we will continue to build ties to and benefit from the experience of other "non-CMAQ" modeling groups. AMAD scientists are leading an international Air Quality Model Evaluation International Initiative (AQMEII). This included organizational activities at a Workshop in April 2009 in Stresa, Italy. One of the goals of this eleven-nation consortium will be to advance approaches for model evaluation and to seek innovative ways of comparing a suite of different regional air quality models from around the world. We have actively solicited the participation of non-CMAQ modelers in the AQMEII project. Extending beyond the realm of regional air quality model evaluation is the Division's involvement in EPA's Council for Regulatory Environmental Models (CREM). CREM brings together an assortment of modeling groups and decision makers from across the Agency. Through our involvement with CREM, we hope to continue to transfer knowledge and experience on model evaluation approaches and techniques. In particular, we hope to learn from other regulatory modeling groups (within and outside of the air program) on how to apply probabilistically-based approaches for understanding model uncertainty and using it in environmental decision making. Finally, the Division sponsors and participates actively in the annual CMAS Conference, which provides a forum for both CMAQ and non-CMAQ modelers to share research findings on model development and evaluation. With respect to diagnostic model evaluation, one of our Division scientists is chairing a special session at this year's CMAS Conference that will discuss instrumented (CMAQ and non-CMAQ) air quality models. These efforts should help establish the scientific credibility of air quality models and their use in policy analysis.

Recommendation: *In considering air quality modeling of the neighborhood scale and hemispheric scale, it would be useful if AMAD could lay out potential revisions and new emphasis in the approaches for model evaluation. For example, in the case of hemispheric modeling and multi-year simulation, a pertinent issue would be how to handle emissions that contribute to long-range transport and formation of target pollutants like ozone. In the neighborhood scale, one issue would be the extent of the spatial and temporal granularity of the pollutants of interest compared to the resolution of the model.*
Response: The extension of the Division's modeling systems to the hemispheric and neighborhood scales introduces extra challenges, especially for model evaluation. As a first step, the Division will be surveying and identifying observational data sets appropriate for evaluating hemispheric and neighborhood-scale models. At a neighborhood-scale, we are leveraging our involvement in the Office of Research and Development's (ORD's) Near-road Research Program by participating in wind tunnel experiments, tracer studies, and urban field studies to improve the characterization of pollution gradients near roadways. We will also review procedures used by other modeling groups that have performed work at these scales to ensure that best practices and observational data will be used. As these surveys and reviews are performed, we will be pinpointing those aspects of model application that need evaluating, so that future evaluation efforts will be targeted to metrics consistent with the regulatory application of the air quality modeling systems.

Recommendation: *Diagnostic analyses of modeled and observed vertical concentrations and wind profiles to assess transport and vertical mixing processes are not only necessary, but long overdue. The role of physical transport has generally been taken for granted and assumed to be taken care of by mass adjustment and artificial diffusion in the numerical methods. This is unfortunate. A careful evaluation of the dispersion characteristics, both vertical and horizontal, within and above the planetary boundary layer is strongly encouraged. Past and planned (if any) field studies with tracer releases should be useful for this purpose.*
Response: Within AMAD, a new task – not discussed at the peer review – is exploring the performance of CMAQ versus vertical profiles of ozone collected by the ozonesonde network. Another ongoing research effort within the Division is an evaluation of atmospheric transport processes, particularly as they affect the vertical profiles of pollutants. The temporal and spatial coverage of vertical ozone data collected by some international aircraft is also being explored to assist with this evaluation. From a meteorological perspective, a collaborative project was started earlier this year with Dr. Jeff Weil of NCAR to review and explore improved techniques for estimating vertical diffusion in the stable boundary. We have also worked with scientists in the national and international communities to identify measurements which are needed to improve our model development and evaluation capabilities. These activities are summarized in articles published in the October 2009 issue of the Air and Waste Management Association's EM Magazine for environmental managers. The articles addressed monitoring approaches from surface-based networks, airplanes, and satellites.

3. Research Theme: Linking Air Quality and Human Health

Recommendation: *AMAD should explore convening a workshop with experts from health and exposure sciences to critically examine the hybrid approach selected by the Division and to consider alternative methodologies.*
Response: We agree with the reviewers that convening a workshop with experts from health and exposure sciences would be very helpful to examine various approaches for fine scale modeling. As a first step, EPA has conducted a 2-day workshop consisting of atmospheric scientists, chemists and exposure and health scientists from the Office of the Research and Development and Office of Air Quality Planning and Standards to consider different approaches for the existing needs. Results from this workshop are being summarized and distributed for further review before being implemented into research plan action items. In addition, AMAD will take steps to closely collaborate with exposure and health scientists as suggested to evaluate and improve such methodologies. For example, EPA is sponsoring three exposure health cooperative programs with Emory University, University of Washington and Rutgers University to apply and develop better tools to link air quality models to exposure models and human health studies. These results have been presented at the August ISEE 2009 Conference in Dublin and at the November 2009 ISEA Conference in Minneapolis. In particular, we will be co-leading a session at the ISEA Conference on "Enhancing Exposure Assessment for Air Pollution Health Studies." These public scientific forums will provide further review of the EPA methodologies and insight on other methodologies available for addressing local-scale exposures to ambient pollutants. Thus, we will expand our discussions with experts from the health and exposure science communities from the internal EPA workshop to experts in academia and to national and international experts. After receiving feedback from these diverse groups, AMAD will revise existing research plans to incorporate new research directions that are relevant to the EPA's mission, have high impact and are feasible within existing resources.

Recommendation: *Develop a guidance document on the use of new approaches developed in the Division to link air quality and exposure models with an emphasis on limitations of these approaches.*
Response: We agree with the reviewers that linking air quality modeling to exposure and health is very important and are planning to be even more active in this research. We communicate the results of our research via peer review publications to make sure that the user community clearly understands the methodology, technical details, and assumptions. For example, mobile sources and near road impact are key components in linking air quality to human health. As a result, we developed better guidance on modeling air quality impacts from mobile sources through publication of the report EPA/600/R-09/001 "Emission and Air Quality Modeling tools for Near-Roadway Applications." This comprehensive report summarizes the state of science on the various algorithms to estimate near roadway concentrations and describes the extensive tests that were made to select the optimal approach to model impacts from mobile sources. Based on the findings of this report, EPA is planning to implement a line source algorithm into the AERMOD model. We will also publish another report showing the results of this research and will assist the Office of Air Quality Planning and Standards in developing detailed guidance documents to the public.

AMAD will continue to document this research through publications in peer-reviewed journal articles, national and international workshops and symposiums. In addition, we have initiated a new research task on model evaluation to identify and document the strengths and limitations of local-scale modeling approaches developed by AMAD and other groups. Finally, we are investigating a joint US/UK workshop on the development of models and methods to improve the simulations of spatial-temporal gradients in urban areas in support of the human health research area.

4. Research Theme: Climate Change - Air Quality Interactions

Recommendations:
- *Guidance to the states is not yet available and feedback should be solicited, in collaboration with OAQPS, from the regions and states as to the type of information needed. There is currently a void in terms of how states and regions account for climate and global changes effects in air quality planning projects.*
- *Attention should be given in further downscaling simulations for documenting the range of results for potential land use and emission changes.*

Responses: AMAD scientists and managers are working closely with the staff of OAQPS on air quality and global climate interactions. The OAQPS and OAR principals investigating the impacts of climate change on air quality are in direct contact with EPA Regions and states regarding climate change implications at the local level. AMAD's

near-term research emphasis on investigating the most credible techniques of downscaling global model climate and air quality results to meso- and regional/local-scales will provide valuable information to regional and urban air quality, ecosystem, and water resource managers on potential climate change, mitigation, and adaptation impacts. AMAD scientists are also collaborating with some of the EPA STAR grants and cooperative agreements looking at regional impacts of mitigation strategies.

The Phase 2 of the current Climate Impacts on Regional Air Quality (CIRAQ) project focuses on the trace gas and particulate implications of climate mitigation strategies including the foreseeable technology improvements expected in the mobile source and electric generation sectors through 2050. Results from this project are expected by the end of 2009. Future research within AMAD will include potential land use and land cover changes resulting from climate change, climate adaptation, and demographic changes projected out to 2100. EPA/ORD is in the process of broadening its climate change program to encompass both climate change and energy production, as a program of broad national significance. Within that context, we will be exploring, for example, the impacts of additional biofuels production not only on direct air and ecosystem quality but also on the implications of changes in land use, fertilizer application, and attendant consequences.

Recommendations:

- *Further work is warranted to complete the initial development of WRF-CMAQ and make it available to the community.*
- *Evaluation of the coupled system will require new thinking about how to evaluate the coupled aspect of the model and to demonstrate its utility. This should include some careful comparisons with WRF-CHEM simulations for a range of conditions.*

Responses: The AMAD model development team has been working over the past year to complete a beta version of the integrated WRF-CMAQ model including the direct effect of aerosol predictions on radiation. We have succeeded in completing this beta version in which the CMAQ model has become a module of the WRF meteorological model, keeping the integrity of each model intact as much as possible to facilitate separate and distinct developmental activities of WRF and CMAQ models. Our plan is to further test, evaluate, and refine this beta version of WRF-CMAQ with the goal of a full public release of the model through the CMAS Center in September 2011. We hope to include some version of the indirect effects of aerosols on cloud microphysics by the time of the release. In the interim we plan to share the code with interested modeling groups to provide us with comments and feedback on the model and its performance.

Evaluation of the unique features of the coupled modeling system is important to show the value added by these feedbacks. Such an evaluation needs a specialized data set, including carefully made particulate matter observations (continuous, size-segregated aerosols), spectrally-resolved radiation, detailed cloud observations, etc. We will be exploring candidate data sets to use in such model evaluations. Meanwhile we do plan to perform model intercomparisons between the WRF-CMAQ and WRF-Chem models, starting with a one-month simulation during August 2006 over the eastern U.S., and expanding the modeling time period through collaborative projects with EPA/OAQPS. We are also exploring collaboration with the Department of Energy on evaluation of the effects of tropospheric aerosol loading on radiation, clouds, and precipitation. We will be comparing the model with observed changes stemming from changes in aerosol precursor emissions over the past two decades.

Recommendation: *Dissemination of these research results should continue to emphasize peer reviewed journals. Global change work would be very appropriate for high impact journals, including the Journal of Geophysical Research, Environmental Science and Technology, and Atmospheric Chemistry and Physics, and this is encouraged.*

Response: We agree with the reviewers' recommendation regarding publishing significant results of our work in peer-reviewed journals. Our intention is to use this medium as the primary path for communicating our results to the science community. We recently published the results of the CIRAQ Phase 1 work: Nolte, C.G., A. B. Gilliland, C. Hogrefe and L.J. Mickley. Linking global to regional models to assess future climate impacts on surface ozone levels in the United States. *Journal of Geophysical Research,* 113(D14307): 1-14 (2008). We will be preparing an article later this year on the CIRAQ Phase 2 results with an emphasis on the PM model results. We have also contributed to a synthesis article of various model investigations of climate impacts on regional ozone concentrations (C. Weaver et al., Bulletin of the American Meteorological Society, 2009). In addition to the journal publications, we are making contributions to assessment reports for EPA and the federal Climate Change Science Program. We thank the reviewers for the specific suggestions of journals to consider for submitting our articles.

Recommendation: *As the Division extends its work to continental and hemispheric scales, new expertise should be added to the Division. Adding expertise and resources may be done in a variety of ways. For example, the Division may form new partnerships (e.g., with NASA on global change), or it might add new staff with targeted expertise, or it might provide significant professional development opportunities for existing staff.*
Response: We agree with the reviewers' recommendation. The community of scientists working on global climate change issues is wide and deep with decades of experience. We want to develop collaborations with this community to take advantage of their knowledge and experience on the global scale issues, while bringing our experience and tools to bear on the linkage and analysis of the continental-regional-local scale issues of air quality and climate change. We are now establishing working relationships with NASA/GISS and Harvard University to interface our WRF and CMAQ mesoscale models with the global Model E and GEOS-Chem models. We have longer range plans of similar collaborations with other modeling groups, such as those at NOAA and the National Center for Atmospheric Research (NCAR), to enable AMAD to take advantage of several global models to inform our regional model simulations. We have also actively recruited post-doctoral fellows to work on our climate team on particular issues, such as global-to-regional downscaling and the interface of global and regional atmospheric chemistry models. We plan to continue to add post-docs, as resources permit, to bring new expertise to the team. One of our initiatives in this area is an Interagency Agreement with NASA which will link to their expertise and facilitate additional staffing support.

5. Research Theme: Linking Air Quality and Ecosystem Health

Recommendation: *AMAD should continue to support ecosystem effects work utilizing CMAQ.*
Response: We thank the reviewers for supporting of our efforts to include CMAQ in ecosystem studies. AMAD has been participating fully in the Ecosystem Services Research Program (ESRP) which will expand efforts to support terrestrial and aquatic ecosystem studies, including biofuels impacts, critical loads, climate change, and NOx-SOx secondary standards studies.

Recommendation: Continued development of the Watershed Deposition Tool is encouraged. *Future developments should consider a process to further reduce the grid scale size of output so that the model can more easily be applied to small watersheds, and incorporation of orographic precipitation effects which greatly influence deposition in complex terrain. Continued development of the Tool should further enlarge the CMAQ modeling community and highlight the usefulness of CMAQ as an ecosystem effects/watershed modeling tool.*
Response: AMAD is continuing to advance the Watershed Deposition Tool, converting it to open source software, making it more flexible by being able to work within an advanced visualization tool and making it easily adaptable to new CMAQ outputs. We understand the need to achieve a reduced grid size. We plan to work with the AMAD model development team to achieve a capability to model at a grid size of 4 km. We will focus on complex terrain while the human health team focuses on urban areas. In the ESRP mapping and nitrogen teams and in the Ad-Hoc Critical Load Subcommittee, there is strong support for AMAD to continue efforts to explore the use of PRISM data to post-process CMAQ results to better treat orographic effects.

Recommendation: *Depending on the direction of future climate change research within EPA, opportunities may arise to link AMAD work with ecosystem change studies. This type of work would provide another avenue (in addition to the climate change – air pollutant effects work) through which CMAQ could prove to be a useful scientific tool. This direction is encouraged if available future funds allow.*
Response: There is strong interest in ESRP to assess the impacts of climate change on ecosystems services and ecosystems. The AMAD ecosystem team plans to work closely with the climate change team to produce deposition and meteorological indicators useful to aquatic and terrestrial ecosystem modelers to assess climate change impacts. We thank the reviewers for their encouragement.

Recommendation: *Continued development of the CMAQ mercury model is encouraged. Since mercury science is at a fairly early stage of development, new reactions and rates are likely to appear often, and this new knowledge and information should be incorporated into the*

mercury model on a regular basis. The recent rejection of CAMR by the court further highlights the need to support the CMAQ mercury model by continued updating in anticipation of likely future mercury policy explorations within EPA.
Response: The reviewers are correct that EPA is considering revisiting the Clean Air Mercury Rule (CAMR). AMAD is completing the incorporation of mercury bi-directional flux algorithms in CMAQ. This will help refine temporal and spatial scales from emissions to deposition (see final Theme 5 recommendation). The AMAD model development team also expects to develop the capability to incorporate additional species associated with sea salt to allow CMAQ to better address bromine (halogen) chemistry in the chemical mechanism. The AMAD model development team will include consideration of mercury in the development of a hemispheric version of CMAQ and expects to review the mercury chemistry as part of that work.

Recommendation: *An increasing body of scientific information suggests strong links between mercury and sulfur deposition in predicting levels of methyl mercury in fish. Future explorations of the mutual roles of mercury and sulfur deposition in mercury bioaccumulation within ecosystems is encouraged. Development of combined sulfur and mercury deposition modeling scenarios using CMAQ would allow researchers a means to test hypotheses about how strongly sulfur deposition affects mercury bioaccumulation.*
Response: AMAD has developed a multi-pollutant version of CMAQ for OAQPS that includes sulfur, nitrogen and mercury along with other pollutants. While the ESRP pollutant focus is nitrogen, the air-water linkage collaboration with the Ecosystems Research Division (ERD) of NERL for the Coastal Carolinas place-based study specifically includes mercury as well as nitrogen. We thank the reviewers for the suggestion to also consider the effect of sulfur on the system. We will attempt to build this into the AMAD air-water collaborative work with ERD.

Recommendation: *Continued mercury model intercomparisons with CMAQ and other leading models are encouraged with an aim of further refining the temporal and spatial scales from emissions to deposition. Such comparisons will help to better bound the geographic range of sources of mercury deposition to ecosystems within the US.*
Response: We agree with the reviewers that model intercomparisons can have value. AMAD expects to act on the lessons from the recent mercury model intercomparison to improve the development of the hemispheric boundary conditions for mercury before launching another intercomparison for mercury. However, we believe the time is ripe for a North American model intercomparison of acidic deposition for critical loads, and AMAD and Canada's Atmospheric Environment Service are proposing to conduct a CMAQ-AURAMS intercomparison. Potentially, a follow-on North American model intercomparison could add mercury.

Appendix A: General Strategic Planning Considerations

(1) Look for where the following converge with our mission/vision/values:
- a. Stakeholders' highest priority needs
- b. AMAD's unique strengths and capabilities
- c. Where we expect to have the biggest impact
- d. Trends and drivers

(2) Assessment
- a. Identify priorities and known drivers
- b. Interview key stakeholders
- c. Interview our staff
- d. Synthesize data to identify themes/directions
- e. Prioritize themes
    1. Pros/cons assessment (include cons of not choosing an option)

	Pros	Cons
Status Quo		
New Project/Program		

(3) Strategic Plan Elements
- a. Where are we now?
    1. mission/strengths/competencies
    2. current and future context (ORD and NERL priorities)
    3. client needs
    4. constraints (resources, political, etc.)
- b. Where do we need to go?
    1. client needs
    2. opportunities
    3. what we believe are growing research areas/needs
    4. what are criteria for deciding priorities and directions
- c. How will we get there?
    1. clarify identity; strategic position
    2. establish long-term strategic goals based on outcomes
    3. establish short-term objectives to achieve goals
- d. How will we know we are on track?
    1. assess progress
    2. maintain awareness of changing environment
    3. minimize structure to maximize flexibility

Appendix B: Strategic Research Planning in AMAD

How do we choose what research to pursue? This set of principles is meant to articulate the general process that we use in AMAD for making decisions on our research priorities.

(1) External guidance
- a. EPA, ORD and NERL (multi-year plans, exposure framework)
- b. Priorities/Initiatives of EPA Administrator, AA, NPDs, NERL Management
- c. Program office/client needs
- d. Scientific community

(2) Division-level guidance
- a. Use of air quality models as "numerical laboratories":
  Perform sensitivity/uncertainty analyses to help guide modeling research
  1. What parameters/processes are model results most sensitive to?
  2. Of those parameters/processes identified in 1, which have the greatest uncertainty?
  3. What parameters/processes have significant influence on modeled? policy options of most interest to decision makers?
  4. Which of the processes identified in 1 and 2, if improved, can help reduce critical uncertainties in the use of modeling results for Agency policy-making?
  5. How can we best communicate the confidence in the use of models in a regulatory setting?
- b. Lessons from model applications and evaluations
  1. What parameters/processes have been identified as flawed, in error, or in need of improvement, based on model evaluation exercises?
  2. Of these parameters/processes identified in 1, which have significant influence on modeled policy options of most interest to decision makers?
- c. Maintain cutting-edge science in air quality models
  1. What are recommendations from Division, BOSC and other Peer Reviews?
  2. What are recommendations from CMAQ Panel Peer Reviews?
  3. What are recommendations from other external reviews?
  4. How do we advance exposure science?
  5. How do we advance integrated trans-disciplinary research?
  6. Participation in collaborative international model evaluation projects (e.g., NAMMIS, AQMEII)
  7. Holding Workshops involving Program Offices and the scientific community to review state-of-science and research priorities
  8. Active participation in NATO/SPS's International Technical Meetings
- d. Building proficient modeling tools and expertise for internal and client applications
  1. Building expertise of AMAD staff and providing scientific leadership
  2. Choosing scientifically-challenging modeling research problems
  3. Focusing on efficiency of modeling system
  4. Mentoring junior scientists in strategic and trans-disciplinary thinking
  5. Ensuring a strong publication record for Division scientists
  6. Ensuring leadership at all levels within the Division