**Advanced Air Quality Modeling System (AAQMS)**

**What is AAQMS?**

EPA researchers are developing the Advanced Air Quality Modeling System (AAQMS). The AAQMS is a multi-configuration modeling system that includes global coverage with seamless mesh refinement and regional domains with or without online coupling of meteorology and air quality (AQ).

**Why AAQMS is Being Developed**

Emerging air pollution problems increasingly require accurate and integrated characterization of near-source features in individual regions and their cumulative impacts on regional pollutant distributions, as well as their interaction with larger scale processes such as intercontinental transport and stratosphere-troposphere exchange. These issues require examination of linked atmospheric dynamical, physical, and chemical processes on scales ranging from local to global and days to multi-decadal. Consistently representing interactions across scales requires consideration of alternative modeling paradigms (seamless grid refinement, online two-way coupling, consistent process representation, minimized redundant calculations) that can address broad community needs for practical applications.

More than a decade ago, EPA linked the Community Multiscale Air Quality (CMAQ) model with the National Center for Atmospheric Research (NCAR) Weather and Research Forecasting model (WRF) to form the WRF-CMAQ two-way coupled system. This coupling enables aerosol information from CMAQ to affect meteorological processes such as radiation and cloud microphysics. The coupled online system also eliminates meteorological temporal interpolation errors that affect offline (sequential) meteorology-AQ systems. NCAR has recently developed a new meteorological model, the Model for Prediction Across Scales – Atmosphere (MPAS-A), which uses a predominantly hexagonal mesh to provide spatial refinement that minimizes discontinuities from regional to global scales. MPAS-A is ideally suited for computationally efficient air quality studies since it conserves mass and can be configured with high resolution for regions of interest with seamless transition to coarser resolution for the rest of the globe.

Extension of the current CMAQ and WRF-CMAQ capabilities to MPAS-A provides a unique opportunity to develop air pollution modeling frameworks that can represent atmosphere-biosphere-chemistry interactions from the local to the global scale in a single system. The AAQMS project entails the coupling of MPAS-A with CMAQ (MPAS-CMAQ) and the unification of coding with the existing CMAQ and WRF-CMAQ frameworks. The result of the AAQMS project is the flexibility of online or offline linking, such as currently exists between WRF and CMAQ, as well as the global refinement capabilities of MPAS-CMAQ. In addition to the scientific advantages of the unified, global MPAS-CMAQ modeling system, the NCAR Mesoscale and Microscale Meteorology (MMM) Laboratory has indicated that development resources will now focus more on MPAS. Thus, development of the MPAS-CMAQ ensures that air quality modeling continues to advance with the state of the science community meteorological model.

**How AAQMS is Being Developed**

AAQMS is being developed in three key areas: the CMAQ model, the meteorological model, and the unified coupler and I/O system. First, CMAQ development will continue by bringing in state-of-the-art science and technology. Second, modifications to WRF and MPAS-A have been made by EPA researchers through external code contributions to include physics options preferred by air quality modelers and implement analysis nudging to improve the suitability of MPAS for long-term retrospective simulations for air quality applications. Third, a unified coupler has been constructed to facilitate data exchange between CMAQ and the meteorological model (either WRF or MPAS-A) in the coupled model configuration, while a new I/O system was also built to accommodate various data formats in different model configurations. With the release of CMAQv6.0, the CMAQ code will fully support its use for MPAS-CMAQ and WRF-CMAQ in both coupled and offline mode.

Regional modeling capability will be facilitated through development of regional MPAS-CMAQ based on the regional version of MPAS-A. Regional MPAS-CMAQ will have reduced model runtime (versus running the entire global model) and will mesh precisely with the global model allowing global-regional connections without any inconsistencies at the boundaries. As a temporary “bridge” between WRF and MPAS-A, and to allow for sufficient time for the MPAS-CMAQ development, new code will be developed to interpolate MPAS-A output to WRF-like output files compatible with the existing CMAQ code for offline CMAQ applications.

In summary, the AAQMS development is synergistic with continuing CMAQ development and leverages advances in both the atmospheric dynamics and chemistry modeling communities by linking the WRF or MPAS-A models with CMAQ effortlessly.

**How AAQMS Will Improve Air Quality Modeling**

The development of MPAS-CMAQ as a configurable component in the AAQMS will help address limitations in traditional multiscale modeling systems, such as inconsistencies in process representations, chemical species mapping, and grid structures between the global and regional models. Currently, multiple grid nesting from hemispheric to local scales adds interpolation errors at every step of refinement. The MPAS-CMAQ modeling system will eliminate these interpolation errors and enable more robust examinations of the impacts of international transport on modulating background concentrations that interfere with attainment of the national ambient air quality standards (NAAQS) and continued progress towards regional haze goals. The AAQMS provides flexibility to the user to build a particular model configuration to study emerging air quality issues or air quality and climate interaction.

**How AAQMS Will be Used**

AAQMS allows users to construct the desired CMAQ modeling system (offline, WRF-CMAQ, or MPAS-CMAQ) to tackle problems with global coverage and regional high resolution in a single simulation or MPAS-CMAQ can be used to provide lateral boundary conditions (LBCs) to a traditional WRF-CMAQ regional configuration. Alternatively, a regional MPAS-CMAQ could replace the regional WRF-CMAQ using LBCs from global MPAS-CMAQ without the need for spatial interpolation.

**AAQMS Tentative Timeline**

* Completed work as of April 2024:
  + Coupled CMAQ with MPAS-A.
  + Completed testing and evaluation of MPAS-CMAQ, including three years (2014-2016) of global coupled MPAS-CMAQ and selected seasons in 2016 of high-resolution global to regional simulations.
  + Submitted pull requests to the MPAS Github repository maintained by NCAR (currently awaiting NCAR to merge these pull requests).
  + Development of a draft manuscript detailing the MPAS-CMAQ system and evaluation (targeted for journal submission in FY24).
  + Completed testing of initial coupling of a global MPAS-A mesh to a “drop-in” regional mesh (meteorology only) for a selected mesh configuration and development of requisite coupling codes.
* Winter 2024/2025: Develop streamlined process/code for creating emission input files for MPAS-CMAQ. Explore development of global EPIC inputs for bi-directional NH3 exchange in MPAS-CMAQ.
* Winter 2024/2025: Complete development and testing of new code to interpolate MPAS-A output to WRF-like output files compatible with the existing CMAQ code as a “bridge” between WRF and MPAS-A (parallel development track with the MPAS-CMAQ development).
* Summer 2025: Incorporate aerosol direct effects on longwave and shortwave radiation into MPAS-CMAQ. *Time required for implementation could be shortened with additional resources*.
* Summer 2025: Complete evaluation of CMAQ results using interpolated MPAS-A output versus traditional WRF output.
* Winter 2025/2026: Complete identification of new model components (e.g., advection in MPAS-A) through which sensitivities would need to be propagated to design and initiate implementation of the Decoupled Direct Method (DDM) and the Integrated Source Apportionment Method (ISAM) in MPAS-CMAQ.
* Summer 2026: Complete initial implementation and testing of urban treatment in MPAS-CMAQ.
* September 2026: Complete prototype of a regional MPAS-CMAQ modeling system.

**Additional Resources**

* Gilliam, R.C., Herwehe, J.A., Bullock Jr, O.R., Pleim, J.E., Ran, L., Campbell, P.C. and Foroutan, H., 2021. Establishing the Suitability of the Model for Prediction Across Scales for Global Retrospective Air Quality Modeling. Journal of Geophysical Research: Atmospheres, 126(10), e2020JD033588.
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* Pleim, J.E., Wong, D., Gilliam, R., Herwehe, J., Bullock, R., Hogrefe, C., Pouliot, G., Ran, L., Murphy, B., Kang, D. and Appel, W., 2018. The new generation of air quality modeling systems. Air & Waste Management Association EM, pp.16-21, https://www.awma.org/emoct18.
* Wong, D. C., Pleim, J., Mathur, R., Binkowski, F., Otte, T., Gilliam, R., Pouliot, G., Xiu, A., and Kang, D., “WRF-CMAQ two-way coupled system with aerosol feedback: software development and preliminary results”, *Geosci. Model Dev.*, 5, 299-312, 2012.

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