Current Research Developments: The Coupled WRF-CMAQ Modeling System

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2009 AMAD Peer Review: Session 4
Climate Change and Air Quality Interactions

Environmental Issue

While changing climate can impact future air quality, tropospheric loading of short-lived gas and aerosol species can also have significant impacts on radiation budgets of the earth-atmosphere system. Scattering of shortwave radiation by aerosols reduces the amount of solar energy absorbed by the earth-atmosphere system, thereby exerting a cooling effect. Organic aerosols and soot absorb radiation, thus warming the atmosphere but cooling the surface. By serving as cloud condensation nuclei (CCN) and enhancing reflectivity of clouds, aerosols can also indirectly effect radiation budgets. Hence, coupled regional meteorology and atmospheric chemistry models are needed to properly characterize the spatial heterogeneity in radiative forcing associated with short-lived aerosol and gases, and, consequently to better understand their aggregate influence on the earth's radiation budgets. Coupled systems are also desirable since they (i) provide consistent treatment of physical processes, reducing redundant calculations, (ii) provide ability to couple dynamical and chemical calculations at finer time-steps, helping modeling at higher horizontal resolutions, and (iii) reduce the disk-storage requirements typically associated with uncoupled sequential operations.

Research Objectives

Develop a comprehensive coupled meteorology-atmospheric chemistry modeling system based on the Weather Research and Forecasting (WRF) and the Community Multiscale Air Quality (CMAQ) modeling systems that is flexible and extensible to address the increasingly complex emerging problems facing the Agency.

Desired Science Attributes

• Coupling the modeling systems provides means for finer scale applications, wherein higher frequency of data exchange between meteorological and chemistry-transport calculations is necessary to better represent the effects of meteorological variability on modeled concentrations.

• Coupling the modeling systems also provides a consistent framework to systematically explore and accurately assess the spatial and temporal variability in perturbations to the earth's radiation balance due to regional aerosol and trace gas forcing.

Desired Structural Attributes

• Maintain integrity of the WRF and CMAQ models, so that both models can evolve independently benefitting from their respective user and development communities

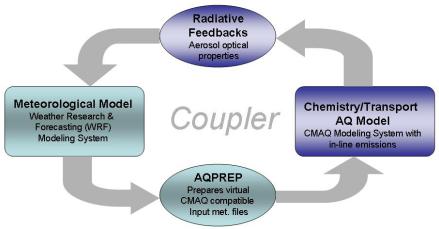
• Support both coupled and the traditional uncoupled modeling paradigms within the same modeling framework to assess their relative benefits for both research and regulatory applications

• Maintain flexibility in design to add feedback process representations

• Ensure efficiency in coupling to enable applications from urban to hemispheric scales

Modeling Approach

Design of WRF-CMAQ Coupled Modeling System



In this design, the WRF and CMAQ modeling systems are coupled through the use of memory resident buffer data files. CMAQ is called from the main "Solve" routine in WRF. The coupler allows for flexibility in time stepping between the two models; CMAQ can be called every WRF time step or any user defined multiple. Additionally, simple switching of the buffer files to disk files allows for identical uncoupled simulation (without feedback). Both models use the same map projections, coordinate systems, and grid structures, thereby ensuring consistent data use across both models. CMAQ has been modified to include meteorology-dependent processes: biogenic emissions, point source plume-rise, and dry deposition velocity estimation, previously calculated upstream of the CMAQ model

Simulated aerosol composition and size distributions are used to estimate the optical properties of aerosols which are then used in the radiation calculations in WRF. Thus, direct radiative effects of scattering and absorbing aerosols in the troposphere estimated from the spatially and temporally varying simulated aerosol distributions, can be fed-back to the WRF radiation calculations, resulting in "2-way" coupling between the atmospheric dynamical and chemical modeling components

Computational Considerations: Though both WRF and CMAQ are designed to run on parallel computing environments, the details of domain decomposition, i.e., mapping of sub-domains and processors, is quite different. The coupler is designed such that these differences in the parallelization and coupling of the models is transparent to the user.

Computational Performance
(1-day simulation; 12km resolution East U.S)

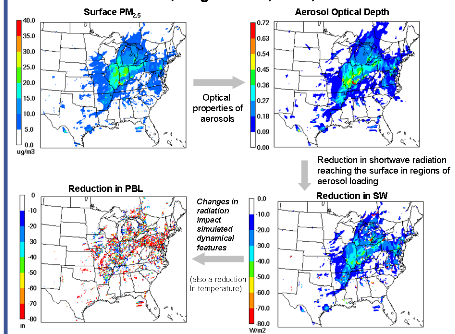
Model	Execution Time
WRF+MCIP+CMAQ (Off-line; 1-hr. communication)	4:45:02
Coupled System (4 min. communication)	5:20:57

Results and Discussion

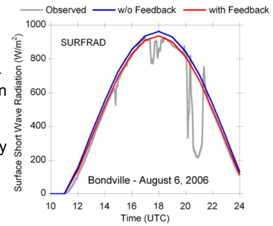
Two sets of initial simulations have been conducted to test the evolving coupled WRF-CMAQ modeling system and to systematically assess the impacts of coupling and feedbacks.

Key questions in application of the coupled modeling system for assessment of air quality-climate interactions are: Can aerosol radiative effects be detected in available measurements? Can such measurements be used to verify the directionality and magnitude of simulated effects?

Case 1: Eastern U.S., August 2-11, 2006, 12 km resolution

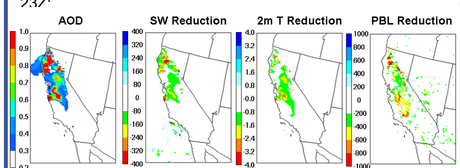


Illustrated above are the direct radiative effects of aerosols simulated by the WRF-CMAQ model at 22Z on August 6, 2006. Inclusion of feedback results in systematically better agreement with shortwave radiation measurements (right).



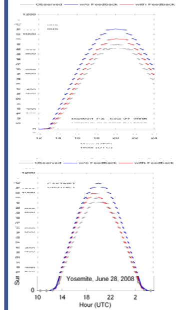
Case 2: California Wildfires, June 20-30, 2008

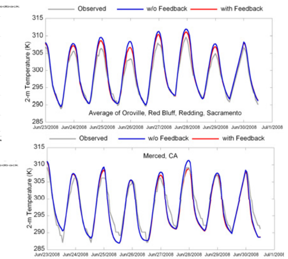
Simulated direct radiative forcing impacts on June 27, 2008 at 23Z:



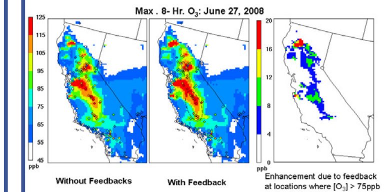
Significant reductions in shortwave radiation, PBL heights, and 2-m temperature are noted in locations impacted by the wildfire smoke plumes.

Verification of feedback impacts at California sites:





Reduction of midday high bias through inclusion of direct aerosol effects



Reduction in PBL heights results in increased O_3. Feed-back effects could have important air quality impacts.

Conclusions and Impact

A prototype 2-way coupled atmospheric modeling system, based on the WRF and CMAQ models, has been developed. Direct feedback of aerosols on shortwave radiation has been successfully implemented. Initial testing suggests that these effects can be large in regions with significant aerosol loading. Preliminary comparisons with limited measurements show improvements in simulation skill for shortwave radiation and 2-m temperature. Inclusion of direct effects leads to suppression of simulated PBL heights which can then impact simulated air quality. This evolving system is expected to play a critical role in the Agency's evolving research and regulatory applications exploring air quality-climate interactions.

Future Directions

• Include aerosol effects on photolysis rates; this will modulate the magnitude of air quality impacts noted in initial testing.
• Investigate the impact of pollution on long-wave radiation.
• Investigate inclusion of indirect feedbacks: aerosol effects on CCN, resolved cloud microphysics, and precipitation
• Verification of results using longer simulations
• Expansion to hemispheric scales: framework to contrast global greenhouse gas forcing and regional aerosol forcing

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