The WRF-CMAQ Integrated On-line Modeling System: Development, Testing, and Initial Applications

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Abstract Traditionally, atmospheric chemistry-transport and meteorology models have been applied in an off-line paradigm, in which archived output on the dynamical state of the atmosphere simulated using the meteorology model is used to drive transport and chemistry calculations of atmospheric chemistry transport model (CTM). A modeling framework that facilitates coupled on-line calculations is desirable since it (1) provides consistent treatment of dynamical processes and reduces redundant calculations, (2) provides ability to couple dynamical and chemical calculations at finer time-steps and thus facilitates consistent use of data, (3) reduces the disk-storage requirements typically associated with off-line applications, and (4) provides opportunities to represent and assess the potentially important radiative effects of pollutant loading on simulated dynamical features. A coupled on-line atmospheric modeling system is developed based on the Weather Research and Forecasting (WRF) meteorological model and the Community Multiscale Air Quality (CMAQ) air quality modeling system. The flexible design of the system facilitates consistent configurations for both on-line and off-line modeling paradigms as well as the systematic investigation of the impacts of frequency of data exchange between the dynamical and chemical calculations as well as feedback effects of chemical concentrations on meteorological process.

1. Introduction

While the role of long-lived greenhouse gases on modulating the Earth's radiative budget has long been recognized, it is now well acknowledged that the increased tropospheric loading of aerosols can also affect climate in multiple ways. Aerosols can enhance reflection of solar radiation both directly, by scattering light in clear air and indirectly by increasing the reflectivity of clouds. On the other hand, organic aerosols and soot absorb radiation, thus warming the atmosphere. Current estimates of aerosol radiative forcing are, however, quite uncertain. The major sources of this uncertainty are related to the accurate characterization of atmospheric loading of aerosols, the chemical composition and source attribution of which is highly variable both spatially and temporally. The accurate regional characterization of aerosol composition and size distribution is critical for estimating their optical and radiative properties and thus in quantifying their impacts on radiation budgets of the earth-atmosphere system. 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. 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.

2. Design of the WRF-CMAQ Coupled Modeling System

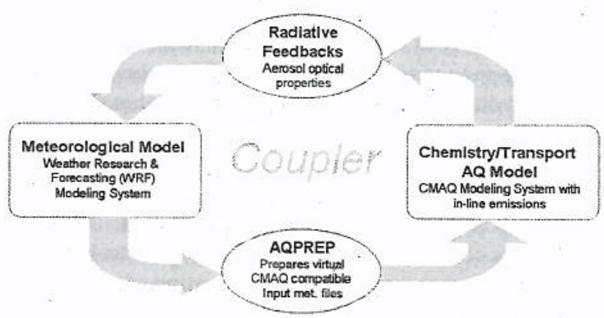

Fig. 1 The coupled WRF-CMAQ modeling system.

The design of the coupled WRF-CMAQ system was based on a number of desired structural attributes: (1) maintain integrity of the WRF and CMAQ (Byun and Schere, 2006) models, so that both models can evolve independently benefitting from their respective user and development communities, (2) 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, (3) maintain flexibility in design to add feedback process representations, and (4) ensure efficiency in coupling to enable applications from urban to hemispheric scales. A schematic the coupling of the WRF and CMAQ modeling systems is shown in Figure 1. 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 (Wong et al., 2009) 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. 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.

3. Results and Discussion

Pleim et al. (2008) previously analyzed the impact of different frequency of coupling between the dynamical and chemical calculations in the coupled WRF-CMAQ system and demonstrated that relatively large differences in simulated instantaneous values compared to an off-line simulation. Figure 2 presents an illustration of the direct aerosol feedbacks simulated by the coupled WRF-CMAQ modeling system over the eastern U.S. In general relatively high aerosol optical depths are noted in regions of high surface and boundary-layer particulate matter pollution. Aerosol direct radiative effects associated with scattering and absorption of incoming radiation, result in a reduction of short-wave radiation reaching the surface, which then translate to reduction in temperature at the surface as well as a reduction in planetary boundary layer (PBL) height. For the moderate pollution levels illustrated in Figure 2, the noted impacts on short-wave reduction and subsequent suppression in boundary-layer heights are relatively modest. As illustrated in Figure 3, the inclusion of direct radiative effects of aerosol loading lead to slight cooling and slightly better agreement with measured values. Application of the modeling system to cases characterized by higher tropospheric $PM_{2.5}$ burden and detailed comparisons with available measurements of short-wave radiation are underway.

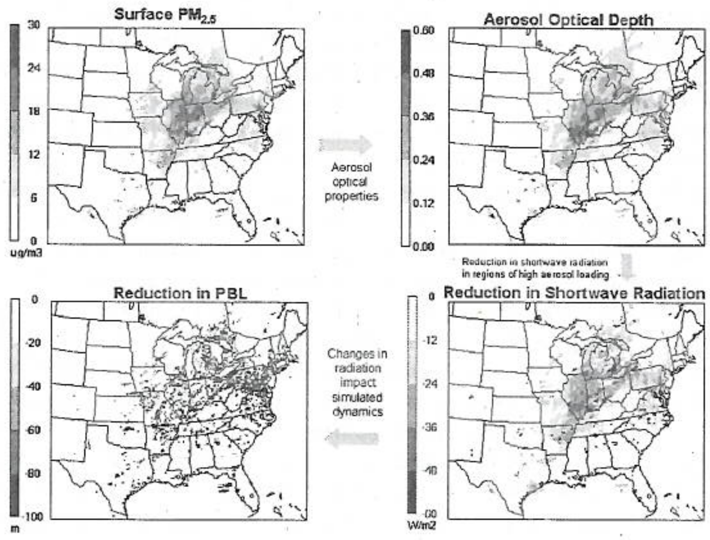

Fig. 2 Illustration of the direct radiative effects of aerosol simulated by the WRF-CMAQ coupled model at 22 UTC on August 6, 2006.

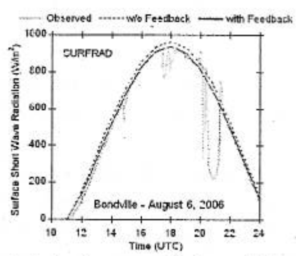

Fig. 3 Comparison of simulated shortwave radiation at the surface with and without direct aerosol feedbacks with measurements at Bondville on Aug. 6, 2006

Disclaimer: Although this paper has been reviewed by EPA and approved for publication, it does not necessarily reflect EPA's policies or views.

References

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