Current Research Developments: The Coupled WRF-CMAQ Modeling System (4.3)

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While the role of long-lived greenhouse gases in modulating the Earth's radiative budget has long been recognized, it is now widely acknowledged that the increased tropospheric loading of aerosols can also affect climate in multiple ways. Aerosols can provide a cooling effect by enhancing 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 quite uncertain. The major sources of this uncertainty are related to the characterization of atmospheric loading of aerosols, the chemical composition and source attribution of which are highly variable both spatially and temporally. Unlike greenhouse gases, the aerosol radiative forcing is spatially heterogeneous and estimated to play a significant role in regional climate trends. The accurate regional characterization of the aerosol composition and size distribution is critical for estimating their optical and radiative properties and thus for quantifying their impacts on radiation budgets of the Earth-atmosphere system.

Traditionally, atmospheric chemistry-transport and meteorology models have been applied in an off-line paradigm, in which archived output describing the atmosphere's dynamical state as simulated by the meteorology model is used to drive the transport and chemistry calculations of the atmospheric chemistry-transport model. A modeling framework that facilitates coupled on-line calculations is desirable because it (1) provides consistent treatment of dynamical processes and reduces redundant calculations, (2) provides the 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. To address the needs of emerging assessments for air quality-climate interactions and for finer-scale air quality applications, AMAD recently began developing a coupled atmospheric dynamics-chemistry model: the two-way coupled WRF-CMAQ modeling system. In the prototype of this system, careful consideration has been given to its structural attributes, to ensure that it can evolve to address the increasingly complex problems facing the Agency. The system design is flexible regarding the frequency of data communication between the two models, and can accommodate both coupled and uncoupled modeling paradigms. This approach also mitigates the need to maintain separate versions of the models for on-line and off-line modeling.

In the prototype coupled WRF-CMAQ system, the simulated aerosol composition and size distribution are used to estimate the optical properties of aerosols, which are then used in the WRF radiation calculations. Thus, the direct radiative effects of absorbing and scattering tropospheric aerosols estimated from the spatially and temporally varying simulated aerosol distribution can be fed back to the WRF radiation calculations; this results in a "two-way" coupling between the atmospheric dynamical and chemical modeling components. This extended capability provides unique opportunities to systematically investigate how atmospheric loading of radiatively important trace species affects the Earth's radiation budget. Consequently, this modeling system is expected to play a critical role in the Agency's evolving research and regulatory applications exploring air quality-climate interactions.