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Modelling two-way interactions between atmospheric pollution and weather using high-resolution GEM-MACH

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The Global Environmental Multiscale (GEM) model is the source of the Canadian government's operational numerical weather forecast guidance, and GEM-MACH is the Canadian operational air-quality forecast model. GEM-MACH comprises GEM and the 'Modelling Air-quality and Chemistry' module, a gas-phase, aqueous-phase and aerosol chemistry and microphysics subroutine package called from within GEM's physics module. The present operational GEM-MACH model is "on-line" (both chemistry and meteorology are part of the same modelling structure) but is not fully coupled (weather variables are provided as inputs to the chemistry, but the chemical variables are not used to modify the weather). In this work, we describe modifications made to GEM-MACH as part of the 2nd phase of the Air Quality Model Evaluation International Initiative, in order to bring the model to a fully coupled status and present the results of initial tests comparing uncoupled and coupled versions of the model to observations for a high-resolution forecasting system.

Changes to GEM's cloud microphysics and radiative transfer packages were carried out to allow two-way coupling. The cloud microphysics package used here is the Milbrandt-Yau 2-moment (MY2) bulk microphysics scheme, which solves prognostic equations for the total droplet number concentration and the mass mixing ratios of six hydrometeor categories. Here, we have replaced the original cloud condensation nucleation parameterization of MY2 (empirically relating supersaturation and CCN number) with the aerosol activation scheme of Abdul-Razzak and Ghan (2002). The latter scheme makes use of the particle size and speciation distribution of GEM-MACH's chemistry code as well as meteorological inputs to predict the number of aerosol particles activated to form cloud droplets, which is then used in the MY2 microphysics. The radiative transfer routines of GEM assume a default constant concentration aerosol profile between the surface and 1500m, and a single set of optical properties for extinction, single scattering albedo, and asymmetry factor. Ozone in GEM is taken from a default 2D (latitude-height) monthly climatology. We have replaced the ozone below the model top with the ozone calculated from GEM-MACH's chemistry, and the default optical parameters associated with particulate matter have been replaced by those calculated with a Mie scattering algorithm.

These changes were found to have a significant local impact on both weather and air-quality predictions for short-term test runs of 24 hours duration. In that particular case, the maximum number concentration of cloud droplets decreased by an order of magnitude, while the number of raindrops increased by an order of magnitude and changed in spatial distribution, but surface rainfall was found to decrease. The differences in meteorology had a profound effect on local pollutant plume concentrations at specific locations and times.

We compare results over a longer time period, using two parallel forecast systems, one with feedbacks between meteorology and chemistry, one without. Both nest GEM-MACH from a North American domain (10 km horizontal grid spacing) to a 1535 x 1360 km, 2.5 km domain. These systems will be evaluated against monitoring networks within the high resolution domain.