EXECUTIVE SUMMARY

Under Texas Air Quality Research Program (AQRP) Project 14-025, Ramboll Environ and collaborators at Texas A&M University (TAMU) incorporated an explicit sub-grid cloud model into the Comprehensive Air quality Model with extensions (CAMx) and evaluated its effects against aircraft measurements logged during two field study campaigns. This report documents the approach, implementation, and testing of the cloud model system. We are providing the new model to the Texas Commission on Environmental Quality (TCEQ); this update will be combined with other modifications and publicly released in a future version of CAMx.

The US Environmental Protection Agency (EPA) requires the use of photochemical grid models to demonstrate how local emission control plans will achieve the federal air quality standard for ground-level ozone in nonattainment areas designated as moderate or higher (EPA, 2014). There are currently two ozone nonattainment areas in the State of Texas but this number will likely increase with the promulgation of a stricter ozone standard in late 2015. TCEQ uses CAMx for both regulatory and research applications.

Daily convective cloudiness and rainfall are common occurrences throughout much of Texas and the southern US during the ozone season (typically April through October). Such convection most often occurs at small scales, and its ubiquity and abundance provide important mechanisms for exchanging boundary layer air with the free troposphere, for chemical processing, and for wet removal. Up to this point CAMx has not explicitly treated cloud processes at scales smaller than the grid resolution (1-10 km). While diagnosed sub-grid cloud fields have been used to parametrically influence grid-scale photolysis rates, wet deposition, and aqueous chemistry, CAMx has not included cloud convective transport.

The new “Cloud-in-Grid” (CiG) treatment includes a new vertical convective transport component for both in-cloud and ambient fractions of the grid column, as well as explicit aqueous chemistry and wet scavenging within the sub-grid cloud compartment. The CAMx/CiG is linked to updates to the Weather Research and Forecasting (WRF) meteorological model’s Kain-Fritsch (K-F) sub-grid cumulus scheme that has been recently improved by EPA’s National Exposure Research Laboratory (NERL). The new algorithm has been thoroughly quality assured, and process testing in serial and parallel modes indicates no substantial impact to overall model speed. The CiG offers two advantages over approaches employed in other off-line photochemical grid models: (1) a direct and consistent link between WRF and CAMx models that removes the need to independently re-diagnose convection location, depth, intensity, and water contents; and (2) the inclusion of both in-cloud convective fluxes and compensating vertical motions in the ambient portion of the cell.

CAMx/CiG was evaluated by applying the model to multi-day episodes in 2008 and 2013 when ozone and precursor concentration measurements were available from aircraft measurement campaigns during the 2008 Stratosphere-Troposphere Analyses of Regional Transport (START08) and the 2013 Deriving Information on Surface conditions from Column and Vertically Resolved Observations Relevant to Air Quality (DISCOVER-AQ), respectively. Specific days

during each episode were selected for the presence of various convective modes. The consequences of convective mixing on the horizontal and vertical distribution of key gas-phase constituents (ozone, nitrogen oxides and carbon monoxide) were qualitatively assessed for plausibility and were compared to aircraft observations in nearby locations and similar times.

We confirm that the convective mixing parameterization produces substantial changes in constituent mixing ratio in areas of model-simulated convection, with smaller yet potentially widespread contributions from regional convection. The CiG generally improves boundary layer simulations of ozone and nitrogen oxides when compared to aircraft-derived profiles. A relative lack of impact at aircraft-sampled locations in the 2008 episode is a consequence of insufficient model-simulated convection rather than any deficiency in the convective mixing parameterization. Based on the project results summarized in this report, we recommend follow-on projects that address additional evaluation and necessary extensions to other areas of the model.