Planetary Boundary Layer Modeling for Meteorology and Air Quality (1.6)

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Air quality modeling systems are essential tools for air quality regulation and research. These systems are based on Eulerian grid models for both meteorology and atmospheric chemistry and transport. They are used for a range of scales from continental to urban. A key process in both meteorology and air quality models is the treatment of sub-grid-scale turbulent vertical transport and mixing of meteorological and chemical species. The most turbulent part of the atmosphere is the planetary boundary layer (PBL), which extends from the ground up to ~1-3 km during the daytime but is only tens or hundreds of meters deep at night.

The modeling of the atmospheric boundary layer, particularly during convective conditions, has long been a major source of uncertainty in numerical modeling of meteorology and air quality. Much of the difficulty stems from the large range of turbulent scales that are effective in the convective boundary layer (CBL). Both small-scale turbulence that is sub-grid-scale in most mesoscale grid models and large-scale turbulence extending to the depth of the CBL are important for vertical transport of atmospheric properties and chemical species. Eddy diffusion schemes assume that all of the turbulence is sub-grid-scale and therefore cannot realistically simulate convective conditions. Simple nonlocal-closure PBL models, such as the Blackadar convective model that has been a mainstay PBL option in NCAR's mesoscale model (MM5) for many years, and the original Asymmetric Convective Model (ACM), also an option in MM5, represent large-scale transport driven by convective plumes but neglect small-scale, sub-grid-scale turbulent mixing. A new version of the ACM (ACM2) has been developed that includes the nonlocal scheme of the original ACM combined with an eddy diffusion scheme. Thus, the ACM2 can represent both the super-grid-scale and sub-grid-scale components of turbulent transport in the convective boundary layer. Testing the ACM2 in one-dimensional form and comparing to large-eddy simulations (LES) and field data from the second and third GEWEX Atmospheric Boundary Layer Study, known as the GABLS2 (CASES-99) and GABLS3 (Cabauw, NL) experiments demonstrates that the new scheme accurately simulates PBL heights, profiles of fluxes and mean quantities, and surface-level values. The ACM2 performs equally well for both meteorological parameters (e.g., potential temperature, moisture variables, and winds) and trace chemical concentrations, which is an advantage over eddy diffusion models that include a nonlocal term in the form of a gradient adjustment.

The ACM2 is in the latest releases of the Weather Research and Forecast (WRF) model and Community Multiscale Air Quality (CMAQ) model and is being extensively used by the air quality and research communities. Comparisons to data from the TexAQS II field experiment show good agreement with PBL heights derived from radar wind profilers and vertical profiles of both meteorological and chemical quantities measured by aircraft spirals.