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Simultaneous nested-grid analysis and forecasting experiments of microscale flows using the NCAR WRF-RTFDDA-LES model

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Many applications rely on accurate weather information in an (range) area of several to few 10s kilometers. For example, wind farm power production, airport aerospace management, wildfire containment, military tests such as those at the seven US Army test ranges, and many others, highly desire accurate 4D microscale weather analysis and forecasts in such small spatial scales. Regional and local scale terrain and underlying land surface properties often impose large impact on the dynamical and thermal forcing and generate fast evolving and highly inhomogeneous microscale flows and weather (such as fog patches). It is observed that winds frequently vary significantly (up to 15 m/s) across a wind farm of a few kilometers. Our knowledge and modeling capabilities about such microscale wind characteristics are very limited. In fact, mesoscale numerical weather prediction (NWP) models, running at $> \sim 1$ km grid sizes, simulate the Boundary Layer processes using column PBL parameterizations that assume equilibrium adjustment for given temperature, moisture, wind and surface fluxes, which is inconsistent to the observed rich and fast evolving microscale flow features. On the other end, large eddy simulation (LES) modeling has recently made a lot of advances for different given weather regime, but few are applied to simulate the real case weather in realistic complex terrain and landscape settings. In this paper, the National Center for Atmospheric Research (NCAR) WRF based Real-Time Four-Dimensional Data Assimilation (RTFDDA) and forecasting system was formulated for simultaneous nested-grid simulation of microscale flows downscaled from the synoptic and mesoscales. RTFDDA permitted effective assimilation of diverse weather observations on the meso- and small scale grids ($DX > \sim 1$km), which provides accurate continuous lateral boundary condition forcing for the LES-scale refined modeling. WRF-RTFDDA-LES was set up with 5 nested-grid domains having grid sizes of $\sim$8.1, 2.7, 0.9, 0.3 and 0.1 km for multi-day simulations of different weather events in several regions in United States. The model results are used to illustrate 1) the WRF-RTFDDA-LES model capability of resolving observed microscale flow structures, 2) the deficiency of mesoscale model/PBL parameterization for the wind shear in the lowest 300m layer, 3) the impact of the model grid resolutions, 4) the more accurate farm-wide wind simulation through the upscaling of the LES modeled circulations, and 5) the overall potential and limitations for real-time microscale weather analysis and forecasting.