Impacts of aerosol-radiation interaction on meteorological forecast over northern China by offline coupling the WRF-Chem simulated AOD into WRF: a case study during a heavy pollution event

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To facilitate the future inclusion of aerosol-radiation interactions in the regional operational Numerical Weather Prediction (NWP) system – RMAPS-ST (adapted from Weather Research and Forecasting, WRF) at Institute of Urban Meteorology (IUM), China Meteorological Administration (CMA), the impacts of aerosol-radiation interactions on the forecast of surface radiation and meteorological parameters during a heavy pollution event (December 6th -10th, 2015) over northern China were investigated. The aerosol information was simulated by RMAPS-Chem (adapted from WRF model coupled with Chemistry, WRF-Chem) and then offline-coupled into Rapid Radiative Transfer Model for General Circulation Models (RRTMG) radiation scheme of WRF to enable the aerosol-radiation feedback in the forecast. To ensure the accuracy of high-frequent (hourly) updated aerosol optical depth (AOD) field, the temporal variations of simulated AOD at 550nm were evaluated against satellite and in-situ observation, which showed great consistency. Further comparison of PM$_{2.5}$ with in-situ observation showed WRF-Chem reasonably captured the PM$_{2.5}$ field in terms of spatial distribution and magnitude, with the correlation coefficients of 0.85, 0.89 and 0.76 at Beijing, Shijiazhuang and Tianjin, respectively. Forecasts with/without the hourly aerosol information were conducted further, and the differences of surface radiation, energy budget, and meteorological parameters were evaluated against surface and sounding observations. The offline-coupling simulation (with aerosol-radiation interaction active) showed a remarkable decrease of downward shortwave (SW) radiation reaching surface, thus helps to reduce the overestimated SW radiation during daytime. The simulated surface radiation budget has also been improved, with the biases of net surface radiation decreased by 85.3%, 50.0%, 35.4%, and 44.1% during daytime at Beijing, Tianjin, Taiyuan and Jinan respectively, accompanied by the reduction of sensible (16.1 W m$^{-2}$, 18.5%) and latent (6.8 W m$^{-2}$, 13.4%) heat fluxes emitted by the surface at noon-time. In addition, the cooling of 2-m temperature (~0.40 °C) and the decrease of horizontal wind speed near surface (~0.08 m s$^{-1}$) caused by aerosol-radiation interaction over northern China helped to reduce the bias by ~73.9% and ~7.8% respectively, particularly during daytime. Further comparison indicated that the simulation implemented AOD could better capture the vertical structure of atmospheric wind. Accompanied with the lower planetary boundary layer and the increased atmospheric stability, both U and V wind at 850hPa showed the convergence which were unfavorable for pollutants dispersion. Since RMPAS-ST provides meteorological initial condition for RMPS-Chem, the changes of meteorology introduced
by aerosol-radiation interaction would routinely impact the simulations of pollutants. These results demonstrated the profound influence of aerosol-radiation interactions on the improvement of predictive accuracy and the potential prospects to offline couple near-real-time aerosol information in regional RMAPS-ST NWP in northern China.