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Assessment of WRF/Chem $PM_{2.5}$ forecasts using mobile and fixed location data from the Fairbanks, Alaska winter 2008/09 field campaign

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ABSTRACT

Weather Research and Forecasting model inline coupled with a chemistry package $PM_{2.5}$ forecasts were assessed using fixed–site $PM_{2.5}$ concentration and specification, and mobile $PM_{2.5}$ concentration and temperature measurements from the Fairbanks winter 2008/09 field campaign. Performance differs with concentrations, varies among months and sites, and best results are achieved for $PM_{2.5}$ concentrations between 15 and 50 μg/m^3. On average over half–a–year and all sites, 24 h–average $PM_{2.5}$ concentrations have a fractional bias and error, and a normalized mean bias and error of 22%, 67%, 13% and 71%, respectively. The skill scores derived from the mobile measurements indicate that high data density increases the representativeness of the observations and enhances the evaluation of spatial details. The model performed well for organic carbon and acceptably for sulfate, but underestimated ammonium significantly.

$PM_{2.5}$ concentrations measured by two different devices at the same site indicate that measurement errors at extremely low temperatures and humidities explain up to 24% of the normalized mean error. Some discrepancies can be attributed clearly to errors in emissions, chemical boundary conditions and meteorology.

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1. Introduction

In the past, photochemical air quality models (AQMs) were not evaluated for use at high latitudes as most air quality issues were related to ozone or particulate matter of diameter smaller than 2.5 μm ($PM_{2.5}$) in low or mid–latitudes. An assessment of AQM performance for high latitudes became necessary when Fairbanks, Alaska was designated a $PM_{2.5}$ nonattainment area (NAA) after the tightening of the 24 h–average National Ambient Air Quality Standard (NAAQS) for $PM_{2.5}$ to 35 μg/m^3 in 2006.

The Fairbanks' nonattainment issue is a local one. Observations combined with HYSPLIT trajectories (Draxler et al., 2009) and photochemical modeling show that the region receives only minor amounts of pollution from long–range transport (Cahill, 2003; Tran et al., 2011). The major sources of primary particulate matter are within the NAA. Typically, $PM_{2.5}$ exceedances occur during strong temperature inversions on calm wind days when the inversion traps local emissions from heating and vehicles near the surface (Tran and Mölders, 2011). Past speciation data indicated that secondary aerosol components constitute about 36% of the $PM_{2.5}$ mass. In ranked order, the most important $PM_{2.5}$ components are organic carbon (OC), sulfate (SO_4^{2-}), elemental carbon (EC), nitrate (NO_3^-), and ammonium (NH_4^+).

Mölders et al. (2011) assessed the performance of the Weather Research and Forecasting model (Skamarock et al., 2008) inline coupled with a chemistry package (WRF/Chem; Peckham et al., 2009) in simulating subarctic boundary layer characteristics of winter 2005/06. They also used data from four aerosol sites, of which two had $PM_{2.5}$ data. They found a strong relation between errors in $PM_{2.5}$ concentrations and temperature errors. Difficulty in simulating the temporal evolution of aerosol concentrations occurred when WRF/Chem mistimed frontal passages or missed to capture sudden temperature changes or the full inversion strength. WRF/Chem largely underestimated NO_3^- at the three remote sites and $PM_{2.5}$ at the polluted site (Fairbanks).

The robustness of any operational evaluation depends on the amount and quality of observations; extensive data from field campaigns provide the best basis for assessing AQM performance (e.g. Djalalova et al., 2010). Until 2008, the State Office Building (SB) was the only $PM_{2.5}$ monitoring site in Fairbanks. In winter 2008/09, the Fairbanks North Star Borough supported a field campaign to assess the situation in the NAA. This dataset provides a first time opportunity to evaluate WRF/Chem for high latitudes over an entire winter. The scope of our study was to analyze WRF/Chem's ability to simulate $PM_{2.5}$ concentration using this data and to assess the suitability of mobile measurements for AQM evaluation.

2. Experimental Design

2.1. Simulations

We used the Alaska–adapted WRF/Chem setup as described in Mölders et al. (2011). This means the WRF–Single–Moment cloud–microphysics scheme (Hong and Lim, 2006), the 3D version of Grell and Devenyi's (2002) cumulus–ensemble approach, the Goddard two–stream, multi–band model, the Rapid Radiative Transfer Model (Mlawer et al., 1997), Janjic's (2002) atmospheric boundary layer and sublayer–schemes, and a modified version of Smirnova et al.'s (2000) land–surface model. Furthermore, Stockwell et al.'s (1990) gas–phase chemical mechanism, Madronich's (1987) photolysis rates calculation, Wesely's (1989) deposition module with the modifications introduced by Mölders et al. (2011), and the Modal Aerosol Dynamics Model for Europe (MADE; Ackermann et al., 1998) and Secondary Organic Aerosol Model (SORGAM; Schell et al., 2001) were used.

The model domain centered over Fairbanks covered Interior Alaska (Figure 1) with a horizontal grid increment of 4 km and a vertically stretched grid to 100 hPa. Analysis was performed on a domain of 80×70 grid points.

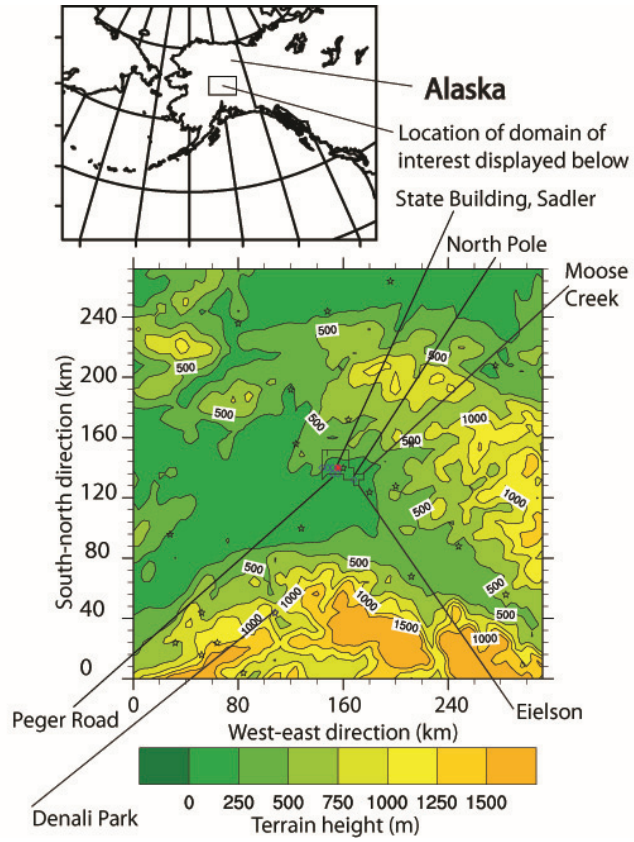

Figure 1. *Location of the interest area and topography therein. Stars, diamonds, and the dot indicate the surface meteorological sites, $PM_{2.5}$ sites and a MET–tower. The polygon marks the NAA.*

Anthropogenic emissions were based on the National Emission Inventory (NEI) of 2008. As the NEI2008 had no point source emissions for the domain at the time of performing the simulation, information, such as emissions provided by the facility operators, was used. Otherwise, we assumed a 1.5%/y increase from the last NEI. Area and line emissions were allocated in space and time depending on relevant data like population density, traffic counts, land–cover, month, weekday, hour, and emission source types. For emissions from traffic, power generation and heating, a temperature dependency was considered that leads to higher (lower) emissions for temperatures below (above) the 1971–2000 mean. Plume–rise was calculated for point emissions following Peckham et al. (2009). Biogenic emissions were calculated following Simpson et al. (1995).

The initial conditions for the meteorological, snow and soil quantities were downscaled from the 1°×1°, 6 h–resolution National Centers for Environmental Prediction global final analyses. This dataset also served to downscale and provide downscaled meteorological boundary conditions. Idealized vertical profiles of Alaska background concentrations for the chemical species served to initialize the chemical fields. Since Fairbanks is far remote from any emission sources, Alaska background concentrations served as chemical boundary conditions.

We ran WRF/Chem in forecast–mode for 10–01–2008 to 04–01–2009 (called OTM hereafter). The chemical distributions obtained at the end of a simulation served as chemical initial conditions for the next simulation, while the meteorology was initialized every five days.

2.2. Observations

The borough made hourly observations of total $PM_{2.5}$ mass using Met–One Beta Attenuation Monitors (BAM 1020) at the SB and Peger Road (PR) for OTM, and a Regional Air Monitoring Systems (RAMS) at two different locations (called RAMS1 and RAMS2) for October 14 to November 3 and November 7 to December 5. They moved the RAMS to three other locations during OTM, but had technical issues. Thus, we excluded this data from the analysis. We determined 24 h–averages from the hourly data as the 24 h–average is relevant for the NAAQS.

Filter based 24 h–average 1–in–3–days $PM_{2.5}$ concentrations obtained with the Federal Reference Method (FRM) exist for the SB, PR, North Pole (NP), and Sadler sites. Speciation data for species contributing to total $PM_{2.5}$ mass collected from filter based 24 h–average concentrations by Met–One Super SASS Speciation Monitors of the Speciation Trends Network (STN) exist every 1–in–3–days at the SB for OTM and at PR and NP for January to March. The SB, NP and PR sites are located in downtown Fairbanks, a mixed commercial–industrial–residential area, and an industrial area, respectively. The Denali Park (DP) Interagency Monitoring of Protected Visual Environments (IMPROVE) site is the only remote site and only site outside the NAA (Figure 1). It has 1–in–3–days $PM_{2.5}$ and speciation data.

The borough took mobile measurements of $PM_{2.5}$ concen–trations and temperatures using vehicles instrumented with a BGI $PM_{2.5}$ sharp–cut–cyclone, sample–liner heaters, Garmin GPS, drycal flow calibrator, and temperature loggers. The vehicles drove along predetermined routes in the NAA on 15, 22, 24, 13, and 12 days in November, December, January, February, and March, respectively, providing 664 000 data points (1 every 2 s).

We performed a quality assurance/quality control (QA/QC) that discarded all temperature and $PM_{2.5}$ data for which the measured temperature deviated more than the 1971–2000 monthly–mean diurnal temperature range from the mean temperature determined from all temperature data of the respective drive. This QA/QC served to discard data taken when the vehicle pulled out and the sensors were still adjusting to the outside air. Since occasionally plumes from trucks or buses that emit at about the sniffer height (~2.44 m), may have hit the sniffer, the QA/QC procedure discarded all $PM_{2.5}$ concentrations that differed >5 $\mu g/m^3$ between two consecutive measurements. We projected the remaining data onto the model grid and averaged over all measurements that were taken in the same grid cell and hour. We compared these hourly–spatially–averaged observations to the hourly volume averages obtained from WRF/Chem.