Episode Selection

Utah Division of Air Quality

1. Introduction

The following meteorological episodes were selected as candidates for Utah's Salt Lake SIP modeling:

- January 1-10 2011
- December 7-19 2013
- February 1-16 2016

These three episodes were selected after careful consultation with atmospheric scientists at the University of Utah (Dr. Erik Crosman, Dr. Chris Foster). These researchers, who have extensive experience simulating Utah wintertime persistent cold air pools, recommended episodes that meet the following atmospheric conditions:

- Nearly non-existent surface winds
- Light to moderate winds aloft (wind speeds at mountaintop < 10-15 m/s)
- Simple cloud structure in the lower troposphere (e.g., consisting of only one or no cloud layer)
- Singular 24-hour $PM_{2.5}$ peak suggesting the absence of weak intermittent storms during the episode

Previous work conducted by the University of Utah and Utah Division of Air Quality (DAQ) showed the four conditions listed above improve the likelihood for successfully simulating wintertime persistent cold air pools in the Weather Research and Forecasting (WRF) model[1].

The goal of the episode selection process is to determine the meteorological episode that helps produce the best air quality modeling performance. The chosen meteorological episode will then be used for SIP maintenance demonstration modeling conducted by Utah DAQ.

Please note that a comprehensive report discussing the meteorology model performance for all three episodes is available at the following URL:

https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/model-improvements/3-wintertime-episodes/DAQ-2017-014342.pdf

[1] https://www.mmm.ucar.edu/weather-research-and-forecasting-model

2. Emissions inventory

A Utah annual emissions inventory for each episode year (2011, 2013 and 2016) was developed by Utah DAQ. Profiles for wintertime temporal adjustments (monthly, weekly, hourly) and VOC/NOx/$PM_{2.5}$ speciation were based on the EPA 2011 Version 6 modeling platform[2]. Spatial surrogate information for population and road networks were developed by Utah at the 4 km and 1.33 km spatial resolution. Other spatial surrogates were adopted from the EPA Clearinghouse for Inventories and Emissions Factors (CHIEF)[3]. Publicly available 2011 National Emissions Inventory (NEI) data was used to populate emissions located inside the modeling domain, but outside of the State of Utah.

3. Model adjustments and settings

In order to better simulate Utah's winter-time inversion episodes different adjustments were made to CAMx input data:

1. Increased vertical diffusion rates (Kvpatch)
2. Lowered residential wood smoke emissions to reflect burn ban compliance during forecasted high $PM_{2.5}$ days (burn ban)
3. Ozone deposition velocity set to zero and increased urban area surface albedo (snow chemistry)
4. Cloud water content reduced during certain days (cloud adjustment)
5. Ammonia injection to account for missing ammonia sources in UDAQ's inventory. This is defined as artificially adding non-inventoried ammonia emissions to the inventoried emissions that are input into CAMx.
6. Reduced the dry deposition rate of ammonia by setting ammonia Rscale to 1. Rscale is a parameter in CAMx that reflects surface resistance.
7. Applied a 93% reduction to paved road dust emissions.

Depending on the episode, different adjustments were applied (Table 1). All adjustments were applied to the January 2011 episode while select adjustments were applied to the other two episodes.

Kvpatch improved overall model performance by enhancing vertical mixing over urban areas.

Snow chemistry modifications, which included reducing ozone deposition velocity and increasing surface albedo over urban areas, helped improve the model performance by better representing secondary ammonium nitrate formation during winter-time inversion episodes in Utah.

Cloud adjustments were only applied to the January 2011 episode, which was characterized by cloud cover on January 6-8 over the Salt Lake and Utah valleys. This cloud cover led to a high bias in sulfate due to the

[2] https://www.epa.gov/air-emissions-modeling/2011-version-6-air-emissions-modeling-platforms
[3] https://www.epa.gov/chief

effect of ammonia on the gas-to-particle partitioning of sulfate in clouds. Application of the cloud adjustment scheme helped reduce this bias.

Ammonia injection was only applied to the January 2011 and February 2016 episode. Ammonia injection values were based on measurements conducted during February 2016. These measurements were used to determine the ammonia injection values for the February 2016 episode. Similar injection values were then assumed for the January 2011 episode.

Rscale modification and burn ban adjustments were also only applied to the January 2011 episode. The burn ban adjustments reflect the compliance rate with the state's two-stage policy ban on wood-burning.

A 93% reduction in paved road dust emissions was only applied to the January 2011 emissions. This adjustment helped improve the model performance for crustal material.

DAQ did not consider applying all adjustments to the February 2016 and December 2013 episodes. Modeled and measured $PM_{2.5}$ were weakly correlated for these episodes, exhibiting different temporal trends with modeled $PM_{2.5}$ peaks not always coinciding with measured peaks. This difference in temporality was mainly driven by the performance of the meteorological model, as will be discussed in more detail later. Applying Rscale modification, paved road dust emissions reduction, burn ban and cloud adjustments as well as ammonia injection would not improve the temporal correlation between measured and modeled $PM_{2.5}$, and therefore the overall model performance, for the February 2016 and December 2013 episodes. The performance of these episodes is primarily driven by the performance of the meteorological model which did not fully replicate the capping inversion during these episodes.

Table 1. Episode-specific adjustments made to CAMx input data.

Episode	**Kvpatch**	**Burn ban adjustments**	**Snow chemistry modifications**	**NH3 injection**	**Rscale modification**	**Cloud adjustment**
January, 2011	200 m for Jan 5-6; 600 m for other days	**Yes**	**Yes**	**Yes**	**Yes**	**Yes**
December, 2013	1200 m	No	**Yes**	No	No	No
February, 2016	1200 m for Feb 1-9; 900 m for Feb 12-16	No	**Yes**	**Yes**	No	No

4. Model performance

CAMx model performance was evaluated for each of the considered time episodes by comparing model outputs to 24-hr PM2.5 mass and speciated measurements. The evaluation is focused on the Lindon monitoring station in the

Provo NAA, which is part of EPA's Chemical Speciation Network and where speciation data gets collected on a 1-in-6 day sampling schedule.

Shown below for each of three episodes are the CAMx performance results for total 24-hour $PM_{2.5}$ mass and $PM_{2.5}$ chemical species, including nitrate (NO_3), sulfate (SO_4), ammonium (NH_4), organic carbon (OC), elemental carbon (EC), chloride (Cl), sodium (Na), crustal material (CM) and other species (other mass).

January 1-10, 2011

A comparison of 24-hr modeled and observed $PM_{2.5}$ during January 1-10, 2011 at the Lindon monitoring station in the Provo NAA showed that the model overall captures well the temporal variation in $PM_{2.5}$ (Figure 1). The gradual increase in $PM_{2.5}$ concentration and its transition back to low levels are generally well reproduced by the model. Moreover, with the exception of January 3-5, the bias between measured and modeled $PM_{2.5}$ is overall relatively small, particularly on $PM_{2.5}$ exceedance days. The large bias on January 3-5 can be mainly related to the meteorological model performance on these days where jet wind speeds were overestimated in the WRF model[4].

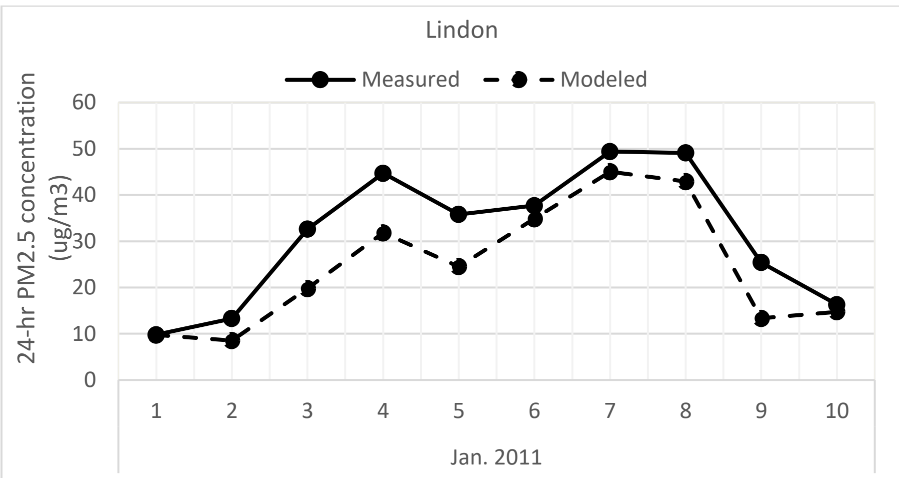

Figure 1. Measured and modeled 24-hr PM2.5 concentrations during January 1-10 2011 at Lindon monitoring station in Provo NAA.

The model performance for $PM_{2.5}$ chemical species was also good for this episode as indicated by a comparison of measured and modeled $PM_{2.5}$ chemical composition at Lindon monitoring station on January 7, which corresponds to a $PM_{2.5}$ exceedance day (Figure 2a-b). Measurements correspond to filter speciation data collected at Lindon during a special air monitoring study in winter 2011.

[4] https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/model-improvements/3-wintertime-episodes/DAQ-2017-014342.pdf

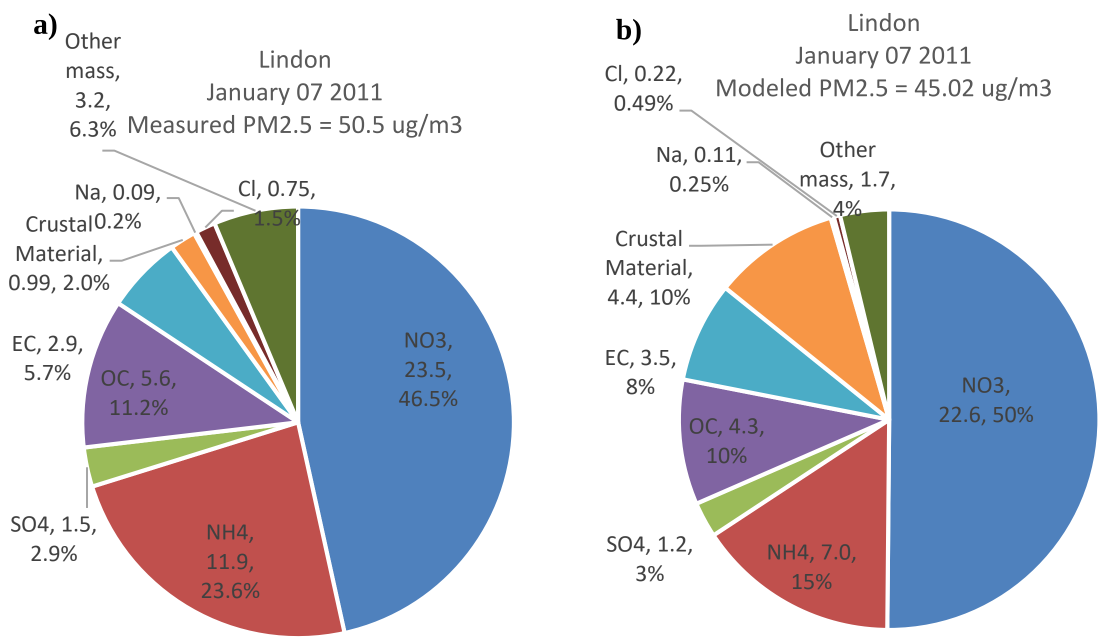

Figure 2a-b. a) Measured and b) modeled chemical composition of 24-hr $PM_{2.5}$ in ug/m3 and % of PM2.5 at Lindon monitoring station in Provo NAA on January 7 2011.

As can be seen, the chemical composition of modeled $PM_{2.5}$ is similar to that of measured $PM_{2.5}$, with modeled secondary species, nitrate, ammonium and sulfate, accounting for over 50% of $PM_{2.5}$ mass, in agreement with measurements. Modeled and observed nitrate concentrations were also in close agreement, accounting for 22.6 and 23.5 ug/m3 of PM2.5 mass. The model, on the other hand, was biased low for ammonium by about 41%, which could be related to an underestimation in modeled hydrochloric acid. The model performance for particulate sulfate was good, with sulfate being biased low in the model by about 20%. The model performance for organic carbon was also reasonably good for January 7, with modeled and observed concentrations contributing to 4.3 and 5.6 ug/m3 of PM2.5 mass. The model, on the other hand, was biased high for EC and CM by about 21 and 72%, respectively.

Overall, the model simulated well the timing and strength of the capping inversion during this January episode. $PM_{2.5}$ chemical species, particularly nitrate, is also well simulated in the model, suggesting that this episode is suitable for modeling.

December 7-19, 2013

The model performance for the December 7-19, 2013 episode was first evaluated for 24-hr $PM_{2.5}$ mass. A comparison of modeled and measured 24-hr $PM_{2.5}$ during this period showed that, while the model generally represented well the temporal variation in $PM_{2.5}$, the model simulated low $PM_{2.5}$ concentrations compared to measurements (Figure 3). This is likely related to a warm model temperature bias in the Utah Valley between December 10-14 due to inadequate simulation of stratus cloud formation during

December 12-14 and inadequate representation of the surface of the Utah Lake. Although frozen in reality during this December episode, the surface of the Utah lake was not represented as frozen in the model[5].

Figure 3. Measured and modeled 24-hr PM2.5 concentrations during December 7-19 2013 at Lindon monitoring station in the Provo NAA.* Federal Reference Monitor (FRM) data is missing for this day. Reported measurement corresponds to data collected with a continuous $PM_{2.5}$ instrument.

To further evaluate the model performance during this episode, modeled and measured $PM_{2.5}$ chemical species on December 12, which corresponds to a $PM_{2.5}$ exceedance day with available speciation measurements, were compared (Figure 4a-b). Nitrate, ammonium and OC are all underpredicted in the model, which is possibly related to the meteorological model performance. The WRF model overpredicted surface temperatures, leading to increased mixing and therefore reduction in concentrations. Moreover, similarly to the model performance for the January 2011 episode, crustal material is overpredicted in the model. An adjustment to paved road dust emissions was not applied for the December 2013 simulations.

Given that the strength of the capping inversion was not well simulated in the meteorological model, selection of the December 2013 episode as modeling episode for modeling demonstration is not desirable.

[5] https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/model-improvements/3-wintertime-episodes/DAQ-2017-014342.pdf

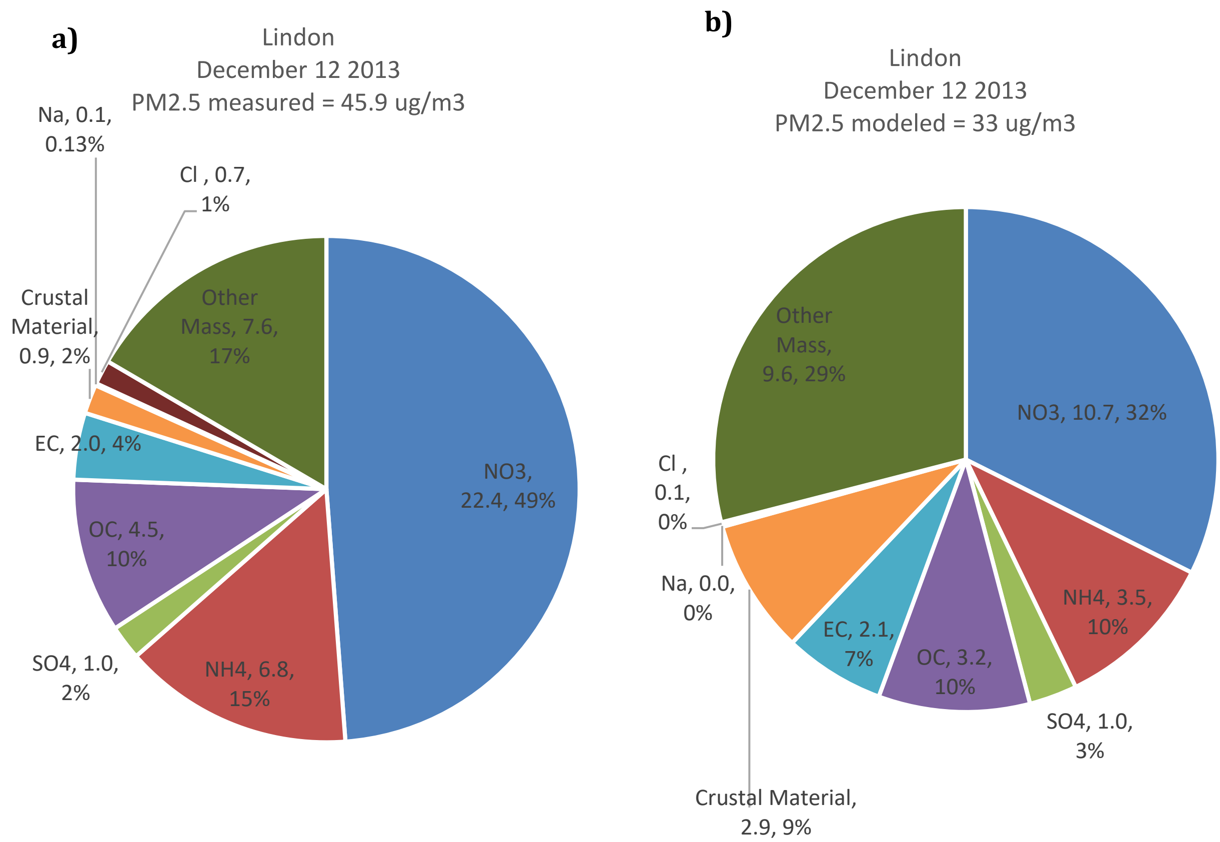

Figure 4a-b. a) Measured and b) modeled chemical composition of 24-hr $PM_{2.5}$ in ug/m3 and % of PM2.5 at Lindon monitoring station in Provo NAA on December 12 2013.

February 1-16, 2016

A comparison of modeled and measured 24-hr $PM_{2.5}$ at the Lindon monitoring station in the Provo NAA during February 1-16, 2016 showed that peak $PM_{2.5}$ concentrations are not well simulated in the model (Figure 5). The increase in $PM_{2.5}$ is not well represented in the model, with $PM_{2.5}$ concentrations building up then dropping prematurely in the model. The model also failed at capturing the observed $PM_{2.5}$ peak on February 14. These results can be attributed to the meteorological model performance. A warm modeled temperature bias in the Utah Valley due to early snow melt-out in the model as well as premature dissipation of simulated clouds likely contributed to increased mixing and early dispersion of $PM_{2.5}$ in the model[6].

[6] https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/model-improvements/3-wintertime-episodes/DAQ-2017-014342.pdf

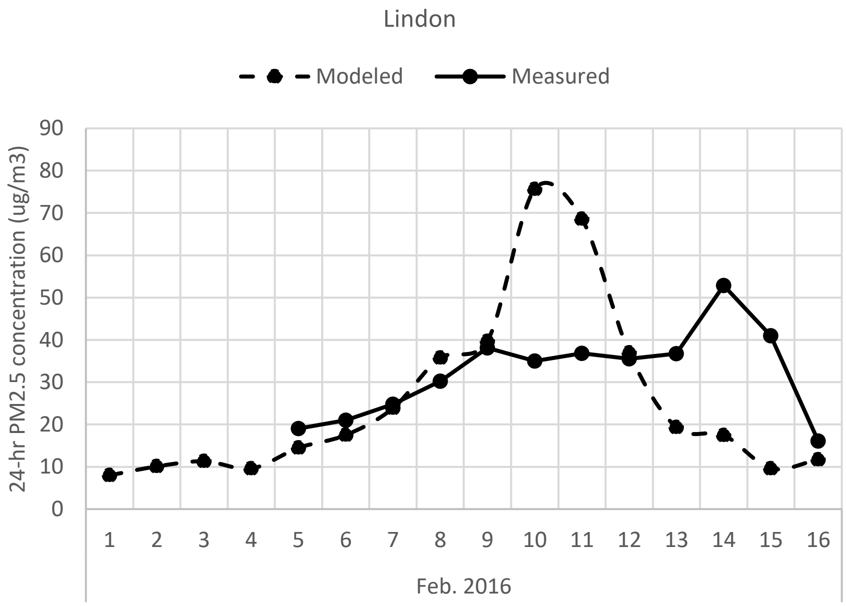

Figure 5. Measured and modeled 24-hr $PM_{2.5}$ concentrations during February 1-16 2016 at Lindon monitoring station in the Provo NAA. FRM data was missing for all episode days. Reported measurements correspond to data collected with a continuous $PM_{2.5}$ instrument.

The model performance for this episode was further assessed for $PM_{2.5}$ bulk chemical species on February 12, which corresponds to a $PM_{2.5}$ exceedance day (Figure 6a-b). Nitrate, a major component of $PM_{2.5}$, was underpredicted by about 25% in the model. Moreover, similarly to the model performance for the two other meteorological episodes, EC and crustal material were overestimated in the model. The model performance for all other species was overall acceptable.

Although the chemical composition of $PM_{2.5}$ on February 12 is overall well reproduced by the model, the timing in $PM_{2.5}$ peaks was generally poorly represented, suggesting that this episode not suitable for modeling.

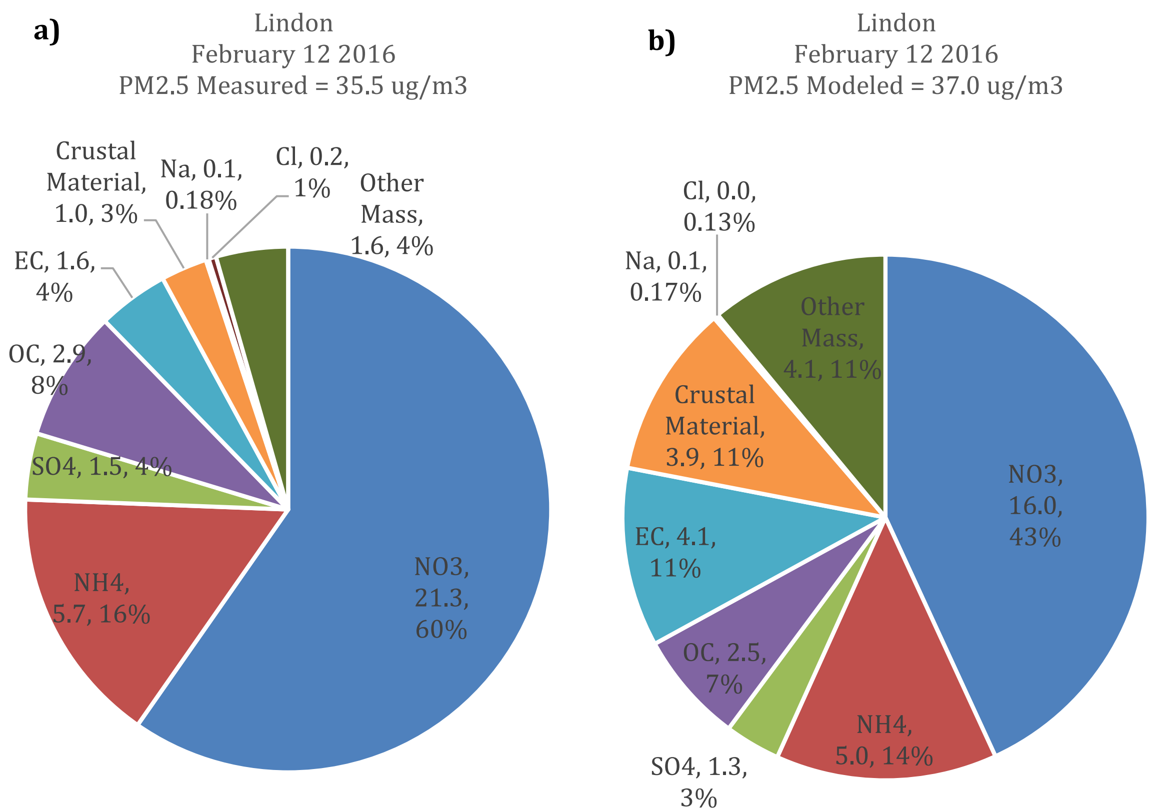

Figure 6a-b. a) Measured and b) modeled chemical composition of $PM_{2.5}$ in ug/m^3 and % of $PM_{2.5}$ at Lindon in the Provo NAA on February 12 2016.

Conclusion

Examining the $PM_{2.5}$ model performance for all three episodes, it's clear that CAMx performed best when using the January 2011 WRF output, which was specifically calibrated to the meteorological conditions experienced during January, 2011; a period that coincided with an exhaustive field campaign (Persistent Cold Air Pool Study (PCAPS)[7]). This was further confirmed by a linear regression analysis that showed that modeled and measured $PM_{2.5}$ at Lindon monitoring station were more strongly correlated during the January 2011 episode (R^2 = 0.89) compared to the other episodes (R^2 = 0.05 and 0.81) (Figure 7). They also displayed a slope that is close to unity (0.87) for the January 2011 episode, further indicating their close agreement and good model performance when using the 2011 WRF output.

[7] http://www.pcaps.utah.edu/

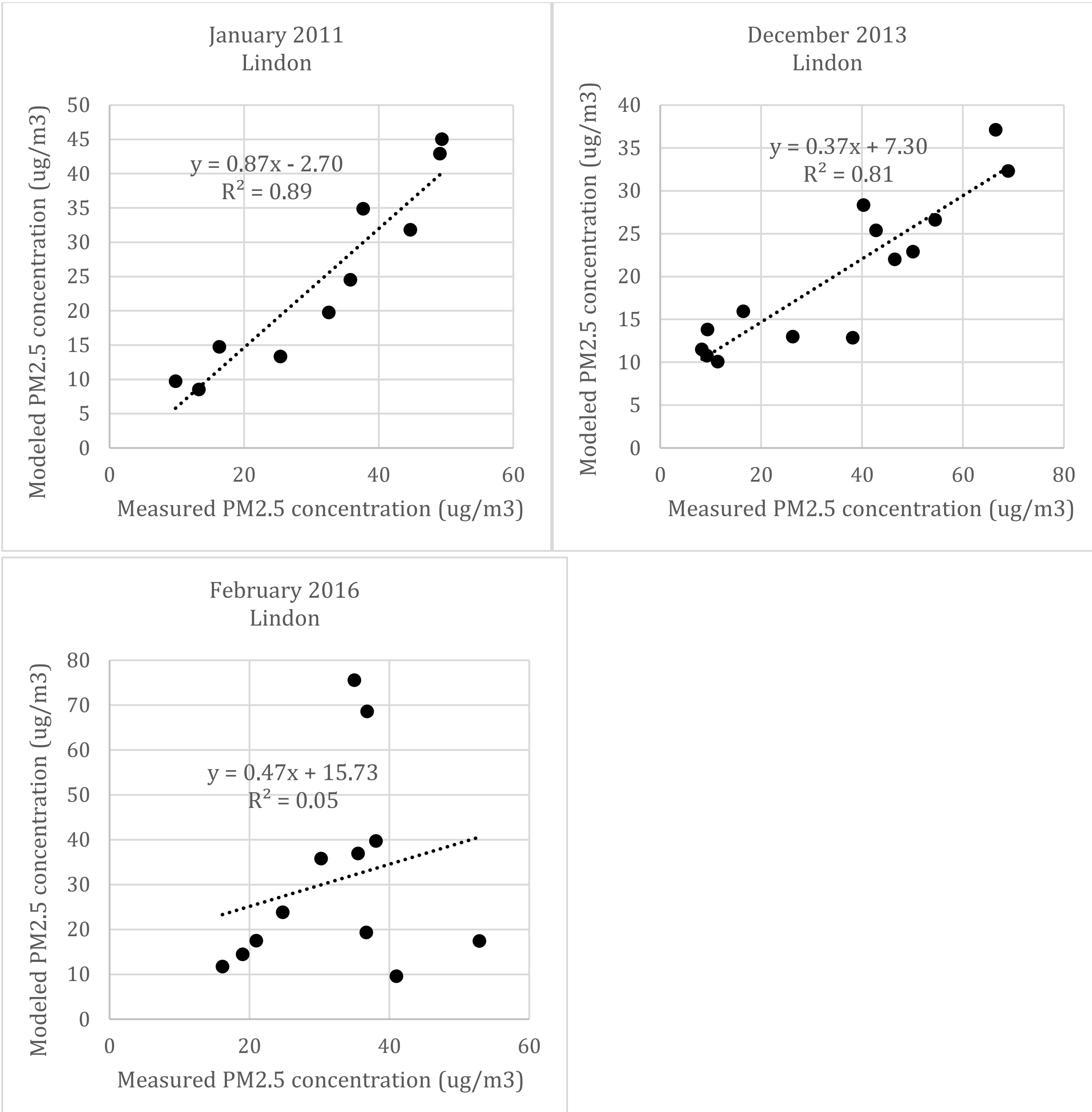

Figure 7. Modeled vs. measured 24-hr $PM_{2.5}$ at Lindon monitoring station for each of the three modeling episodes: January 2011, December 2013 and February 2016. Dots represent each individual day of the modeling episode. Linear regression fits (dashed line) and equation are shown for each episode.

Given that the January 2011 WRF data produced superior model performance when compared with the other two episodes, UDAQ selected the January 2011 episode to conduct its modeled maintenance demonstration work.