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 meteorological 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 six 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. 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.
5. Reduced the dry deposition rate of ammonia by setting ammonia Rscale to 1. Rscale is a parameter in CAMx that reflects surface resistance.
6. Applied a 93% reduction to paved road dust emissions.

Depending on the episode, different adjustments were applied. 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.

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.

---

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

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.

UDAQ 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 adjustment 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 Dec. 31 and Jan 1-2.	**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 Logan and Smithfield monitoring stations in the Logan non-attainment area (NAA).

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 Logan monitoring station in the Logan 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. However, despite the overall good representation of the temporal variation of $PM_{2.5}$, concentrations are generally biased low in the model, particularly on January 4-9, 2011, which can be related to the meteorological model performance on these days. Temperature was overestimated by 5-15 ^{o}C in the meteorological model during this period and thick low-level clouds were simulated on January 5 while clouds were not observed on this day[4].

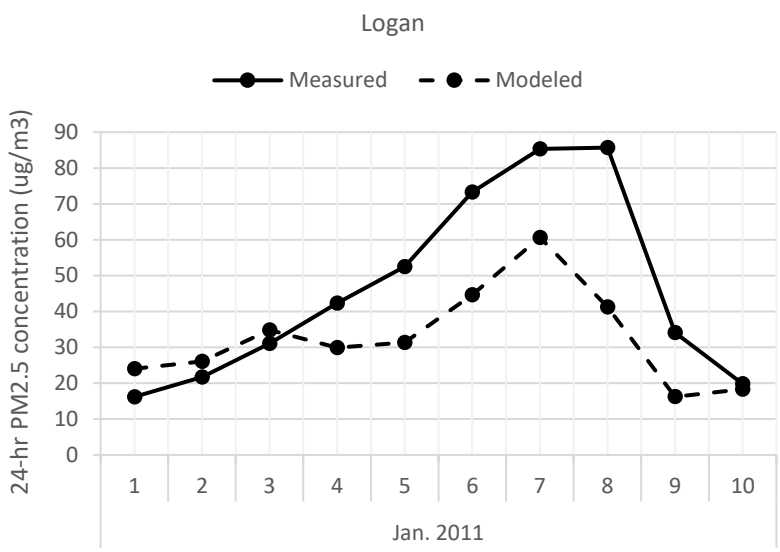

Figure 1. Measured and Modeled 24-hr $PM_{2.5}$ Concentrations During January 1-10 2011 at Logan Monitoring Station in the Logan NAA.

The model performance for $PM_{2.5}$ species was overall good. Figure 2a-b shows a comparison of modeled and measured $PM_{2.5}$ chemical species on January 7, which corresponds to a $PM_{2.5}$ exceedance day. The model performance for sulfate was reasonably good, with measured and modeled sulfate accounting for 3 and 5% of PM2.5 mass, respectively. The model also underestimated nitrate and ammonium, which is partly related to the meteorological model performance where temperature was overestimated by 5-15 ^{o}C in WRF during January 4-10, 2011, as aforementioned. The underestimation in modeled nitrate and ammonium can also be related to an underestimation in modeled hydrochloric acid (HCl) and oxidants sources (more details are provided in the TSD). The model, on the other hand, overall overestimated crustal material, EC and OC. The overprediction in these species on days when the simulated atmospheric mixing was particularly strong, suggests that this overestimation is potentially related to an overestimation in their source emissions. It is, however, noteworthy that despite these biases in modeled $PM_{2.5}$ species, modeled nitrate and ammonium account for most of the $PM_{2.5}$ mass, in agreement with measurements.

[4]PM2.5 State Implementation Plan Meteorological Modeling, available at https://documents.deq.utah.gov/air-quality/planning/technical-analysis/research/model-improvements/3-wintertime-episodes/DAQ-2017-014342.pdf

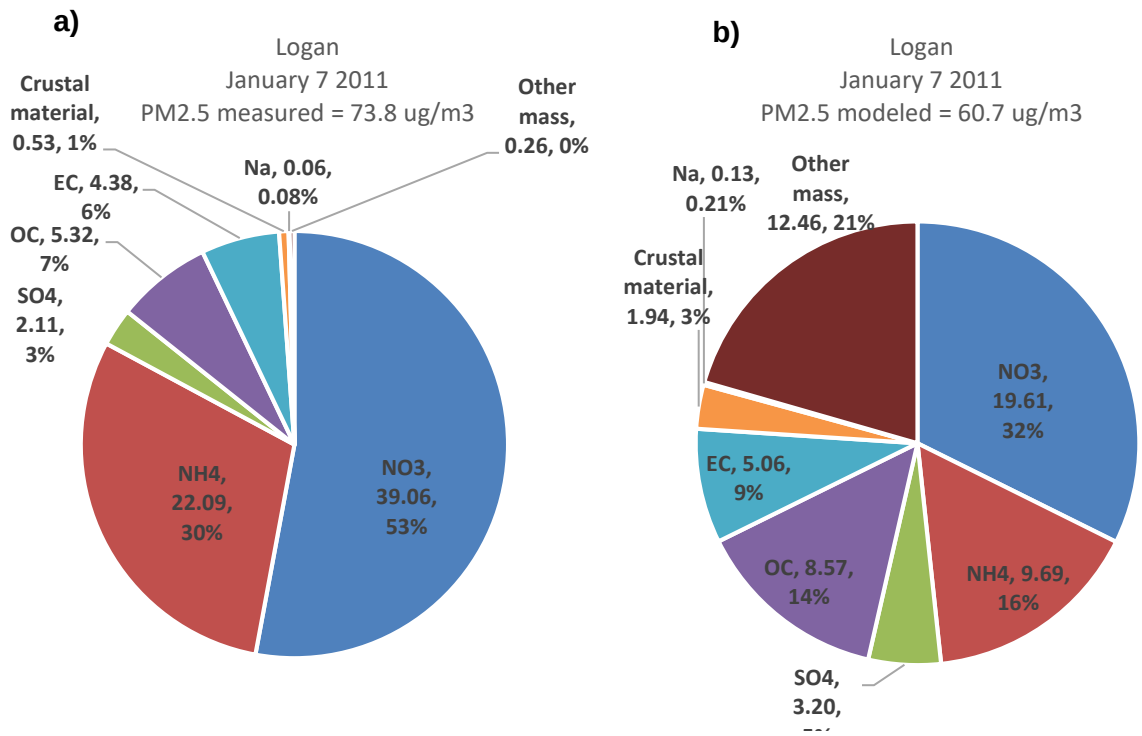

Figure 2a-b. Measured (a) and modeled (b) chemical composition of 24-hour $PM_{2.5}$ in ug/m3 and percent of $PM_{2.5}$ at Logan monitoring station on January 7 2011

Overall, the model simulated well the timing of the capping inversion during this January episode. PM2.5 chemical species are also reasonably well simulated in the model, suggesting that this episode is suitable for modeling.

December 7-19, 2013

A comparison of modeled and measured 24-hr $PM_{2.5}$ at Logan during the December 7-19 2013 episode showed that the model did not represent well the temporal variation in PM2.5 and the capping inversion (Figure 3). While observations show a peak in $PM_{2.5}$ concentrations on December 14, CAMx is simulating a drop in $PM_{2.5}$ levels. This can be attributed to the meteorological model performance, where the model did not properly capture the cold overnight low temperatures that were observed on this day[5].

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

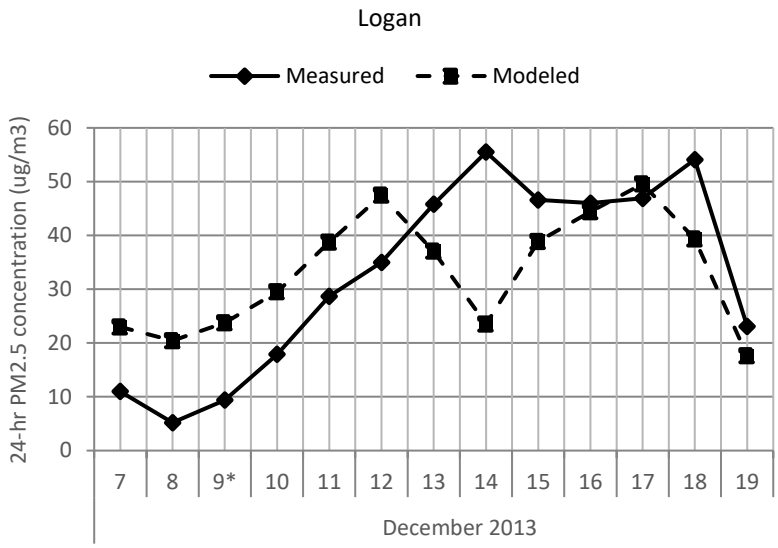

Figure 3. Measured and modeled 24-hr $PM_{2.5}$ concentrations during December 7-19 2013 at Logan monitoring station in the Logan NAA.

The model performance for $PM_{2.5}$ chemical species was overall poor for this episode as indicated by a comparison of measured and modeled $PM_{2.5}$ chemical composition at Logan monitoring station on a $PM_{2.5}$ exceedance day (Figure 4a-b). Given that measurements of $PM_{2.5}$ chemical species were not available for a $PM_{2.5}$ exceedance day during the December 7-19 modeling episode, this analysis is based on a comparison of the fraction of individual $PM_{2.5}$ chemical species in total $PM_{2.5}$ mass between 2013 model outputs and measurements from 2011. Measurements correspond to filter speciation data collected at Logan during a typical winter-time inversion event in 2011. As can be seen, nitrate and ammonium are both significantly underpredicted in the model, which can be related to the meteorological model performance, where WRF overpredicted surface temperatures, leading to increased mixing. 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 in the December 2013 simulations. OC was also overestimated in the model while the performance for sulfate and EC was reasonably good.

Given that $PM_{2.5}$ species were poorly represented in this episode and that the strength of the capping inversion and timing of the $PM_{2.5}$ peaks were not well simulated, selection of the December 2013 episode for the maintenance demonstration modeling is not desirable.

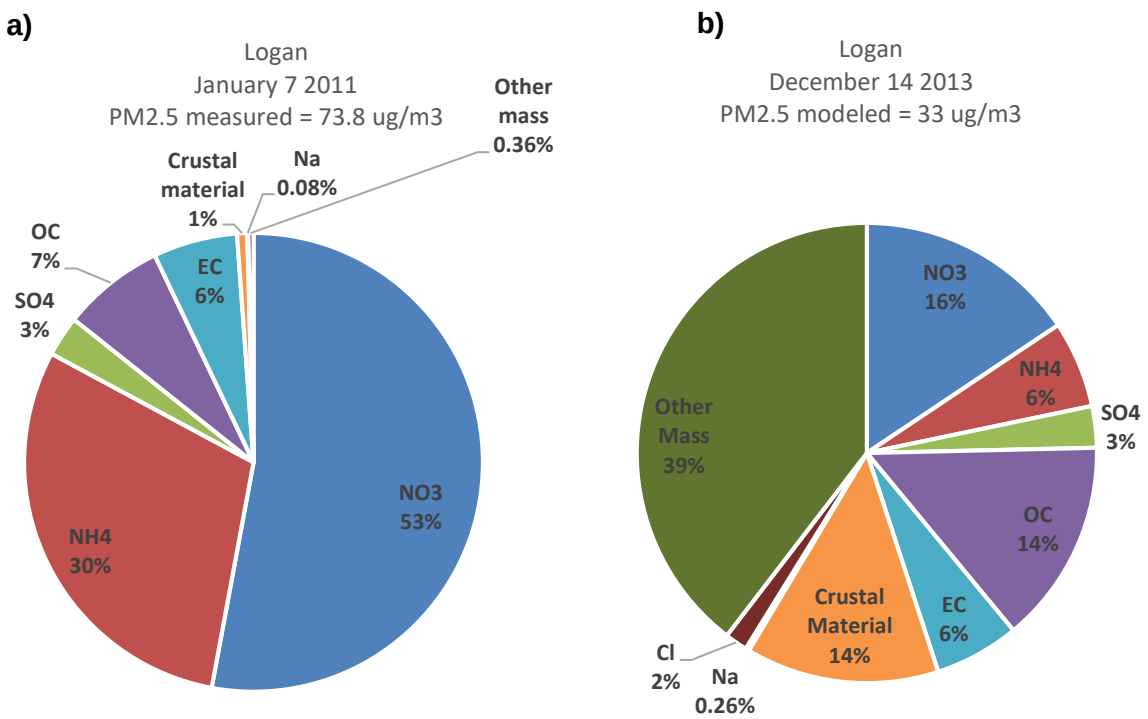

Figure 4a-b. a) Measured and b) modeled species contribution (in %) to $PM_{2.5}$ at Logan monitoring station in the Logan NAA on a typical 24-hr $PM_{2.5}$ exceedance day

February 1-16, 2016

A comparison of modeled and measured 24-hr $PM_{2.5}$ at Smithfield monitoring station in the Logan NAA shows that $PM_{2.5}$ concentrations are biased low in the model (Figure 5). The timing of the $PM_{2.5}$ peaks is also poorly simulated. This can be mainly related to the meteorological model performance. A warm modeled temperature bias in the Cache Valley due to early snow melt-out and premature dissipation of simulated clouds in the model likely contributed to increased mixing and dispersion of $PM_{2.5}$ in the photochemical model[6].

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

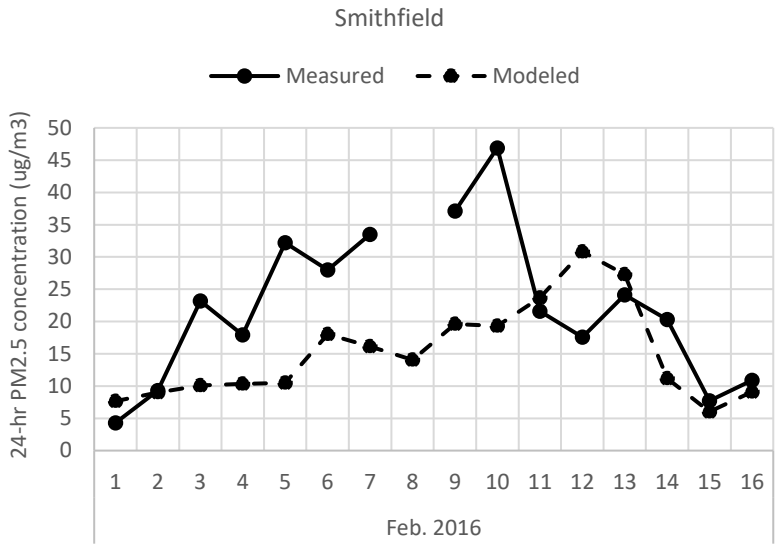

Figure 5. Measured and modeled 24-hr $PM_{2.5}$ concentrations during February 1-16 2016 at Smithfield monitoring station in the Logan NAA. Note that FRM filter data was missing for February 8, 2016.

The model performance for $PM_{2.5}$ chemical species was overall weak for this episode as indicated by a comparison of measured and modeled $PM_{2.5}$ chemical composition at Logan monitoring station on a $PM_{2.5}$ exceedance day (Figure 6a-b). Given that measurements of $PM_{2.5}$ chemical species were not available for a PM2.5 exceedance day during the February 1-16 modeling episode, this analysis is based on a comparison of the fraction of individual $PM_{2.5}$ chemical species in total $PM_{2.5}$ mass between 2016 model outputs and measurements from 2011. Measurements correspond to filter speciation data collected at Logan during a typical winter-time inversion event in 2011. As can be seen, nitrate and ammonium are both underpredicted in the model, which can be partly related to the meteorological model performance, where WRF overpredicted surface temperatures. Moreover, similarly to the model performance for the January 2011 episode, EC and crustal material are overpredicted in the model. An adjustment to paved road dust emissions was not applied in the February 2016 simulations.

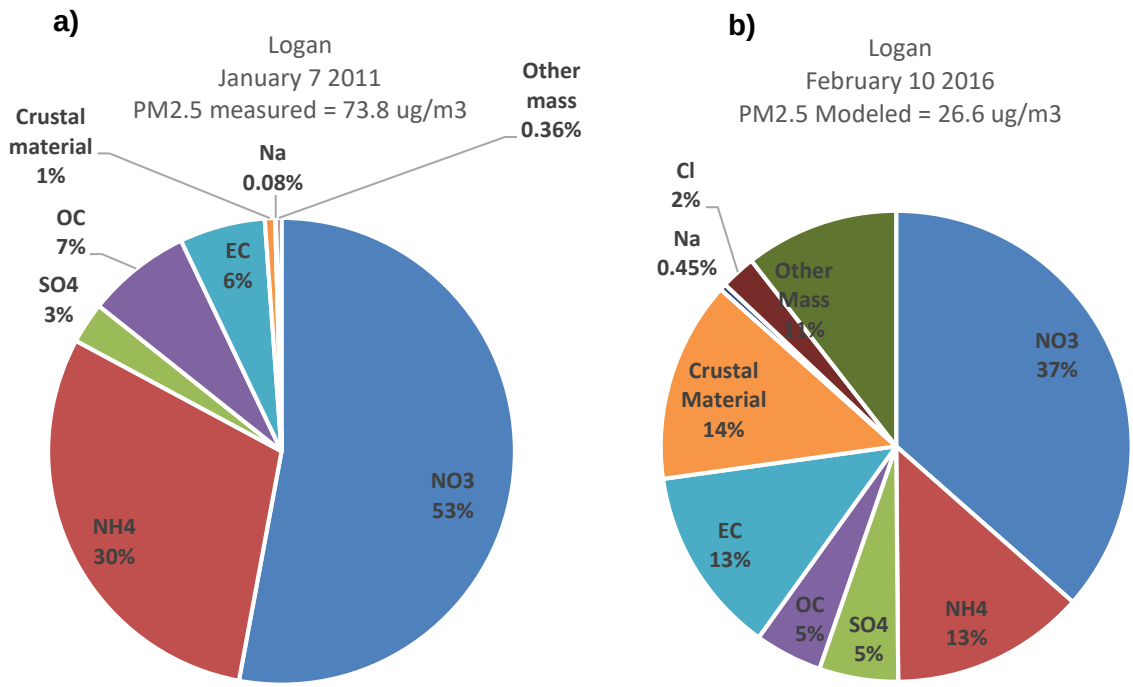

Figure 6a-b. a) Measured and b) modeled species contribution (in %) to $PM_{2.5}$ at Logan monitoring station in the Logan NAA on a typical 24-hr $PM_{2.5}$ exceedance day

Given that $PM_{2.5}$ species and total mass are not well simulated and that the timing of the $PM_{2.5}$ peaks is poorly represented in the model, this episode is not suitable for maintenance demonstration modeling.

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 the Persistent Cold Air Pool Study (PCAPS)[7], an exhaustive field campaign. This was further confirmed by a linear regression analysis that showed that modeled and measured $PM_{2.5}$ at the Logan monitoring station were more strongly correlated during the January 2011 episode (R^2 = 0.72) compared to the other two episodes (R^2 =0.18 and 0.39) (Figure 7).

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.

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

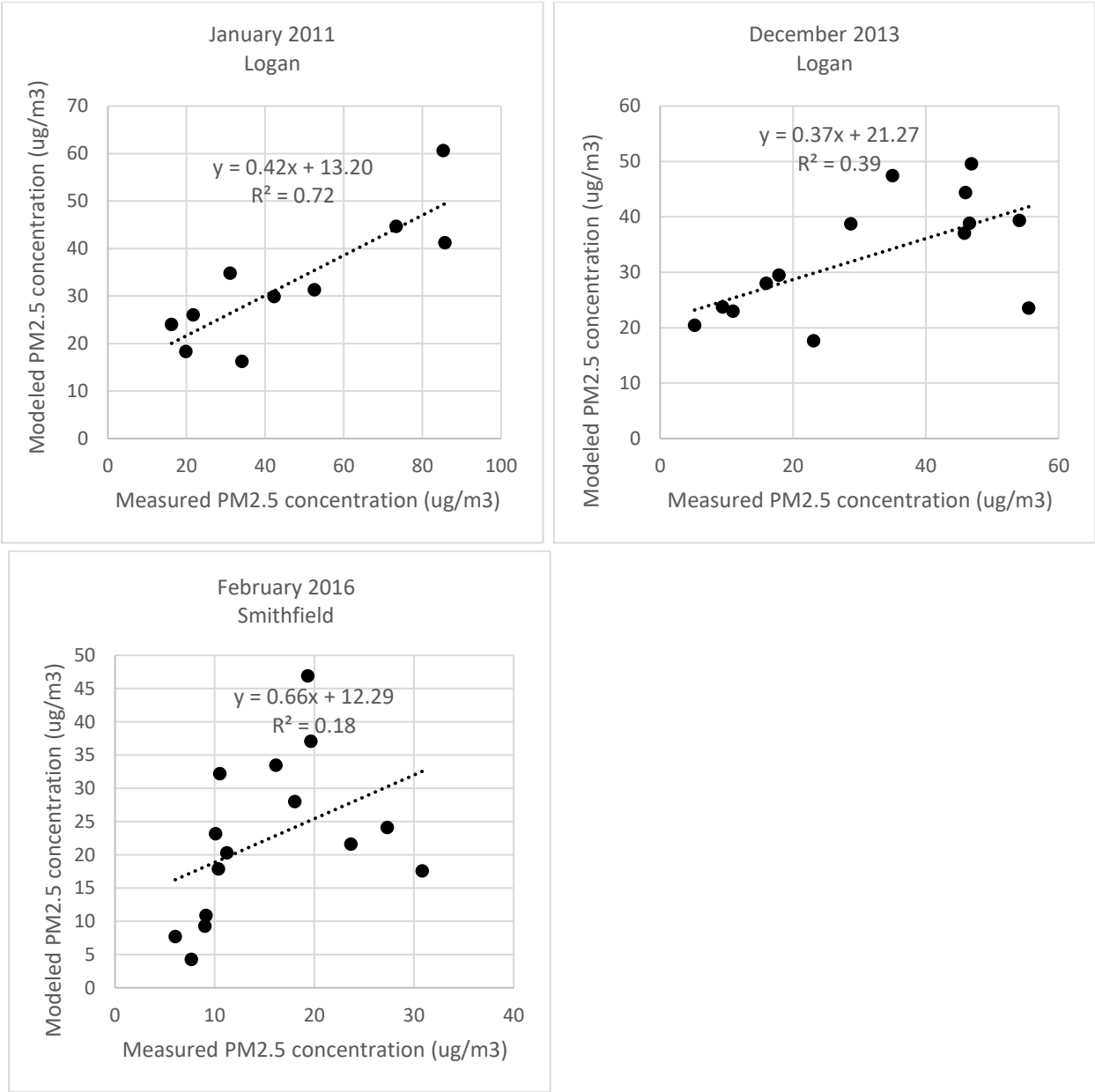

Figure 7. Modeled vs. Measured 24-hr $PM_{2.5}$ for each of the three modeling episodes: January 2011, February 2016 and December 2013. Dots represent each individual day of the modeling episode. Linear regression fits (dashed line) and equation are shown for each episode.