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.

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

[3] https://www.epa.gov/chief

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 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 Hawthorne monitoring station in the SLC NAA, which is part of EPA's Chemical Speciation Network and where speciation data gets collected on a 1-in-3 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 Hawthorne monitoring station in the SLC 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. An overestimation in $PM_{2.5}$ is observed on January 3rd, which is most likely related to the meteorological model performance on this day. Thin mid-level clouds, which were observed on January 3-4, were not simulated in the WRF model, leading to an increasingly stable low-level boundary layer, limiting the mixing of pollutants[4]. To help reduce this bias, Kvpatch was applied. The underestimation in PM2.5 on January 5 2011, at the Hawthorne station is also related to the meteorological model performance on this day, where the WRF model overestimated the wind shear near the mixing height[5].

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

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

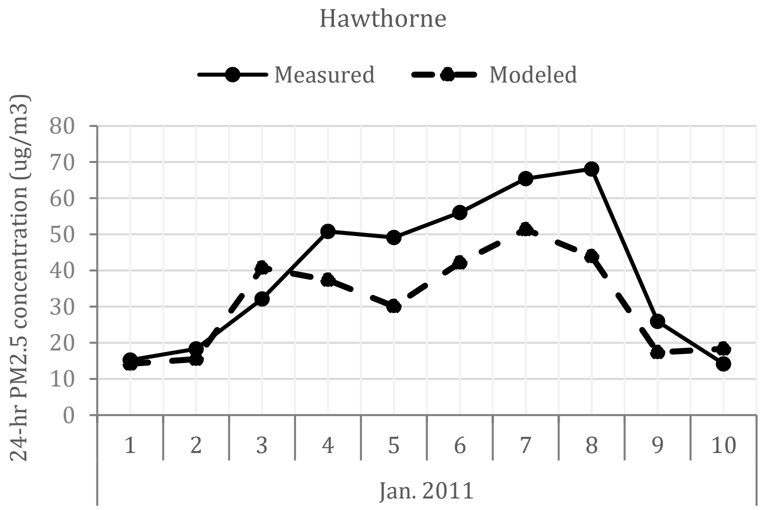

Figure 1. Measured and Modeled 24-hr $PM_{2.5}$ Concentrations During January 1-10 2011 at Hawthorne Monitoring Station in SLC NAA

The model performance for $PM_{2.5}$ chemical species was also good for this episode. The chemical composition of modeled $PM_{2.5}$ on January 7, which corresponds to a $PM_{2.5}$ exceedance day, 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 (Figure 2a-b). Ammonia injection helped improve the model performance for these species. The model also performed well for OC while it overestimated crustal material and EC, possibly due to an overprediction in their source emissions. While a 93% reduction in paved road dust emissions was applied, it is possible that further reduction was needed.

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

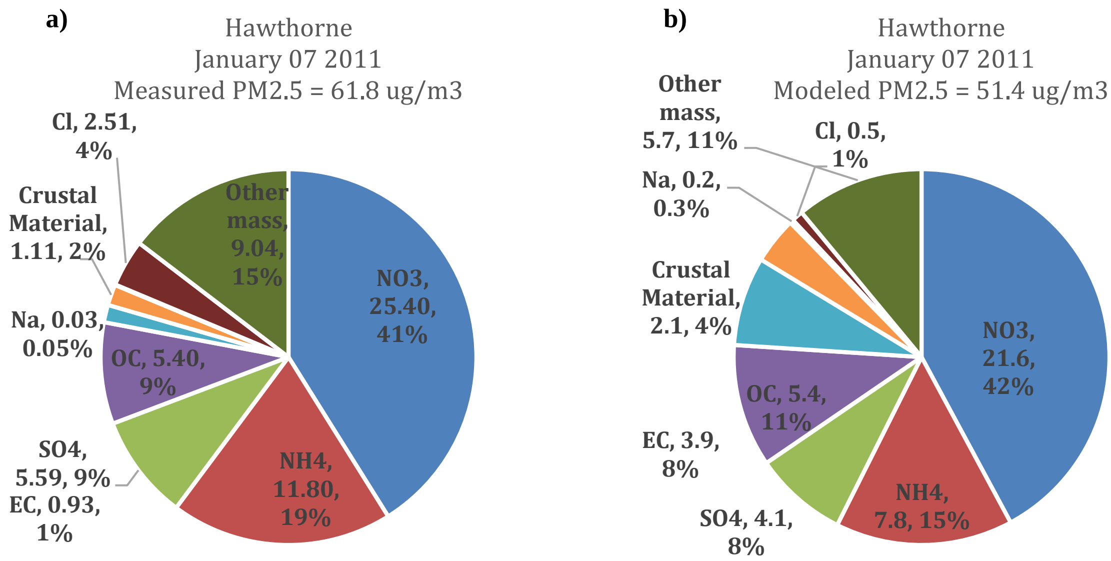

Figure 2a-b. a) Measured and b) Modeled Species Contribution (in ug/m3 and %) to $PM_{2.5}$ at Hawthorne Monitoring Station in the SLC NAA on a Typical 24-hr $PM_{2.5}$ Exceedance Day.

December 7-19, 2013

A comparison of modeled and measured 24-hr $PM_{2.5}$ at Hawthorne during the December 7-19 2013 episode showed that the model did not represent well the temporal variation in $PM_{2.5}$ and the capping inversion (Figure 3). While observations show peak $PM_{2.5}$ concentrations during December 14-15, CAMx is simulating a drop in $PM_{2.5}$ levels. This can be attributed to the WRF model not properly capturing the cold overnight low temperatures that were observed on these days[6].

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

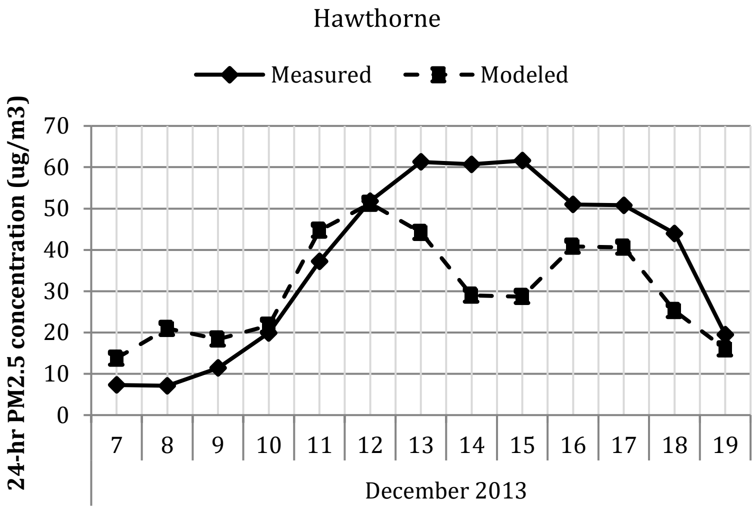

Figure 3. Measured and Modeled 24-hr $PM_{2.5}$ Concentrations During December 7-19, 2013 at Hawthorne Monitoring Station in the SLC NAA.

To further evaluate the model performance, modeled and measured $PM_{2.5}$ chemical species on December 15, which corresponds to a $PM_{2.5}$ exceedance day with available speciation measurements, were compared for Hawthorne (Figure 4). Nitrate and ammonium are both underpredicted in the model, which can be partly 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 for the December 2013 simulations. Cl was also underestimated in the model while the performance for sulfate and OC was acceptable.

Given that the strength of the capping inversion and timing of the $PM_{2.5}$ peaks were not well simulated, using the December 2013 episode for the modeling demonstration is not desirable.

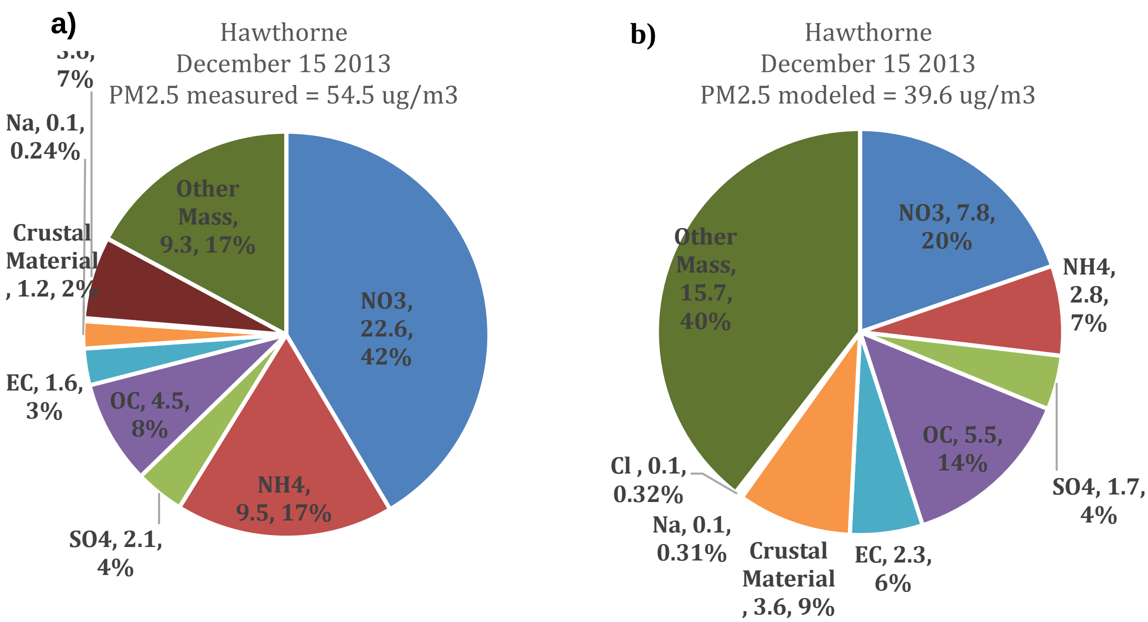

Figure 4. a) Measured and b) Modeled Chemical Composition of 24-hr $PM_{2.5}$ in ug/m^3 and % of PM2.5 at Hawthorne Monitoring Station in SLC NAA on December 15 2013.

February 1-16, 2016

A comparison of modeled and measured 24-hr $PM_{2.5}$ at Hawthorne monitoring station (Figure 5) shows that $PM_{2.5}$ concentrations are generally biased low in the model and $PM_{2.5}$ drops off prematurely in the model. This can be related to the meteorological model performance, where the mixing height was overestimated due to performance issues related to clouds and fog formation. While fog and low clouds were observed during February 9-15, WRF was unable to properly capture the timing of the fog and clouds formation[7].

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

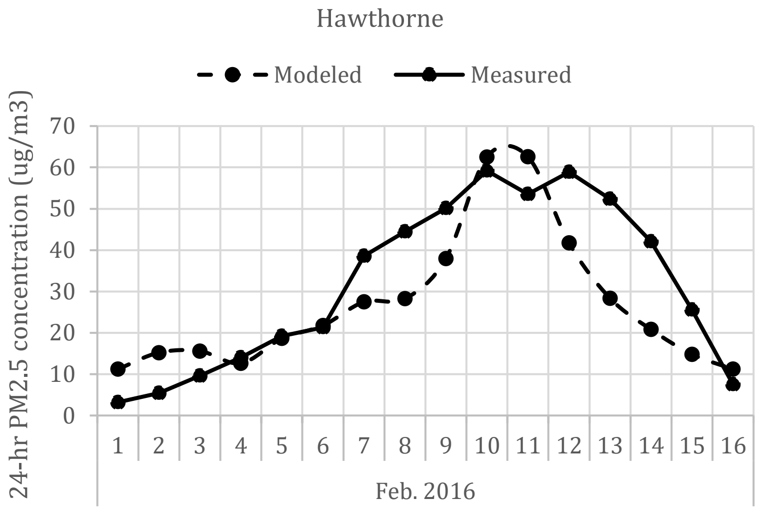

Figure 5. Measured and Modeled 24-hr $PM_{2.5}$ Concentrations During February 1-16, 2016 at Hawthorne Monitoring Station in the SLC NAA.

To further evaluate the model performance, modeled and measured $PM_{2.5}$ chemical species on February 12, which corresponds to a $PM_{2.5}$ exceedance day, were compared for Bountiful monitoring station (Figure 6). Complete speciation measurements were not available for Hawthorne. As can be seen, nitrate, ammonium and sulfate were underpredicted in the model. Moreover, similarly to the model performance for the two other episodes, EC and crustal material were overestimated in the model.

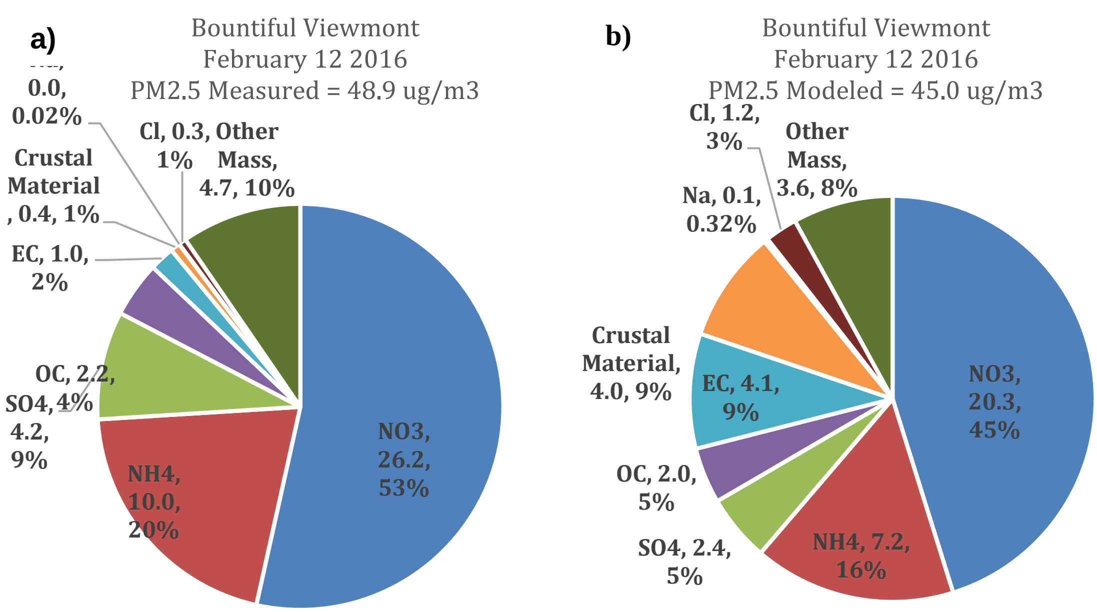

Figure 6. Measured (a) and modeled (b) chemical composition of 24-hour $PM_{2.5}$ in μg/m^3 and percent of $PM_{2.5}$ at Bountiful monitoring station on February 12 2016.

Given that the model is not able to sustain the observed $PM_{2.5}$ peaks, this episode is less suitable for modeling compared to the 2011 episode.

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 focused on the Salt Lake Valley (Persistent Cold Air Pool Study (PCAPS)[8]). The superior model performance for the January 2011 episode was further confirmed by a linear regression analysis that showed that modeled and measured $PM_{2.5}$ at Hawthorne monitoring station were more strongly correlated during the January 2011 episode (R^2 = 0.80) compared to the other episodes (R^2 = 0.54 and 0.69) (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.

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

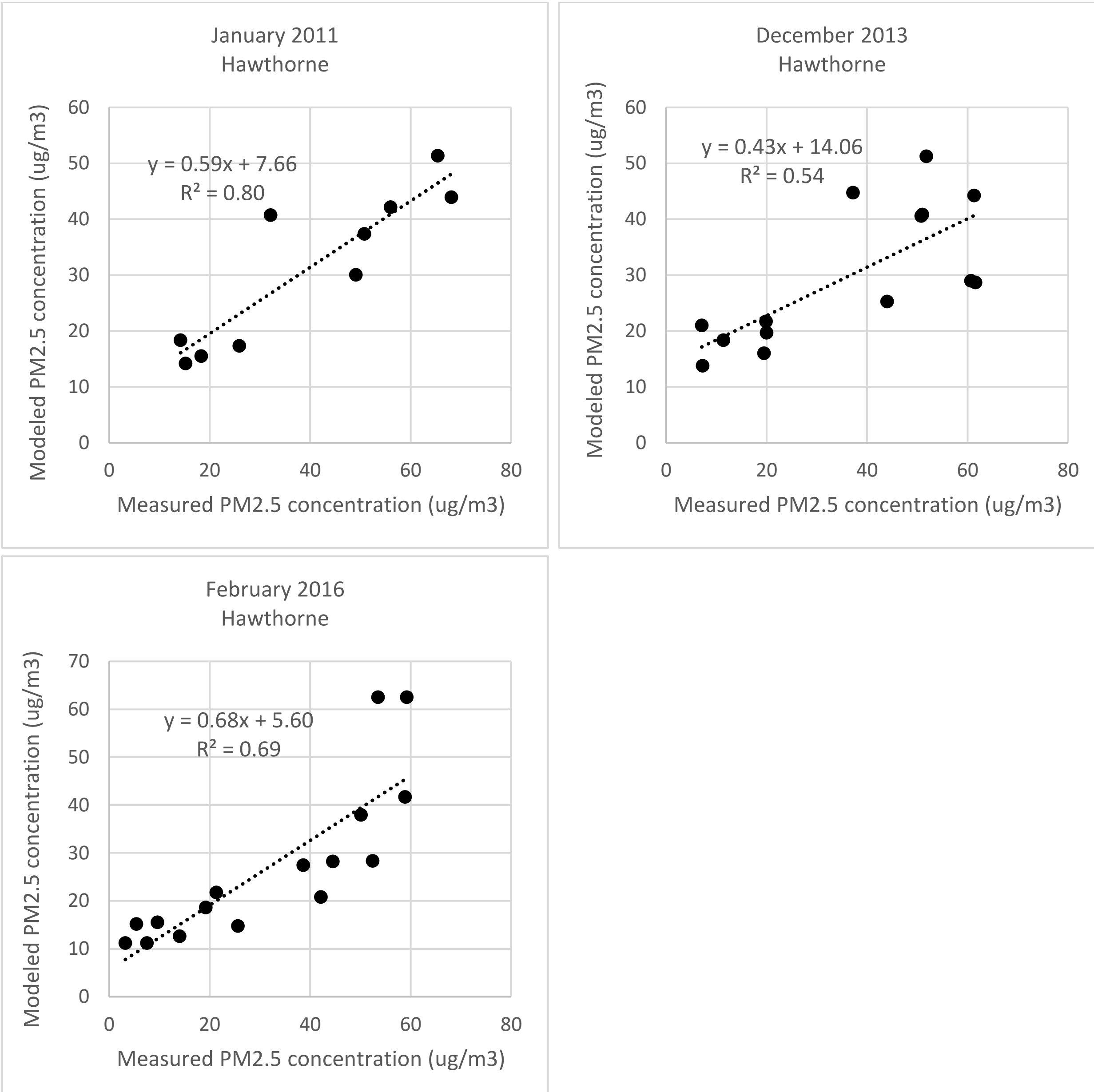

Figure 7. Modeled versus measured 24-hr $PM_{2.5}$ at Hawthorne monitoring station for each of the three modeling episodes: January 2011, December 2013 and February 2016. Dots represent each individual day of the modeling episode. Linear regression fits (dashed line) and equation are shown for each episode.