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, 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. Utah DAQ is using the the CAMx 6.30 photochemical model (Ramboll). The chosen meteorological episode will then be used in the 2017 serious SIP attainment demonstration modeling conducted by Utah DAQ.

Please note that a comprehensive report discussing the meteorology model performance for all three episodes is available from Utah DAQ 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

In this section, we list the adjustments Utah made to CAMx input data to better simulate Utah's wintertime 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. Cloud water content reduced during certain days (cloud adjustment)
5. Ammonia injection to account for missing ammonia sources in DAQ'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.

Depending on the episode, different adjustments were applied (Table 3.1). All adjustments were applied to the January 2011 episode while select adjustments were applied to the other two episodes.

Kvpatch and snow chemistry modifications were applied to all three episodes. Using the Kvpatch processor (Ramboll), Utah increased the minimum vertical diffusion rate within a certain depth from the surface. The depth was chosen based on the episode-specific model performance in 24-hour $PM_{2.5}$. CAMx modeling showed a high bias in primary aerosol concentrations for all three 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 wintertime 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

All other adjustments were only applied to select episodes. 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.

Cloud adjustments were only applied to the January 2011 episode, which was characterized by a cloud cover on January 6-8 over the Salt Lake Valley. 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.

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.

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, 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.

Episode	Kvpatch	Burn ban adjustments	Snow chemistry modifications	NH3 injection	Rscale modification	Cloud adjustment
January, 2011	200 m for Jan 4-5; 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

Table 3.1: Episode-specific adjustments made to CAMx input data.

4. Model performance

In this section, we only show speciated results for Hawthorne. Hawthorne is one of two Chemical Speciation Network sites in the Salt Lake Valley (the other being Bountiful in Davis County, to the North). Hawthorne is more appealing to use for evaluating model performance for two reasons:

- Higher sampling frequency: Hawthorne samples every one-of-three days compared to Bountiful, which samples one-of-six days. This is important as Hawthorne captures more peak $PM_{2.5}$ days.
- Consistently higher $PM_{2.5}$ measurements.

For each of three episodes, we will show CAMx performance for total 24-hour $PM_{2.5}$ concentrations. Of the limited speciated Air Quality System (AQS) data available, we chose one peak $PM_{2.5}$ day per episode to represent high wintertime $PM_{2.5}$ composition.

4.1. January 1-10, 2011

For the January meteorological episode, CAMx performance in 24-hour $PM_{2.5}$ is generally good at Hawthorne. However, the earlier part of the modeled episode at Hawthorne is impacted by the absence of thin mid-level clouds that were present during January 3-5. The absence of clouds here had the effect of warming the surface and increasing the mixing height in the simulation. Kvpatch depth was lowered during this period to account for this, while keeping modeled primary aerosol concentrations reasonable.

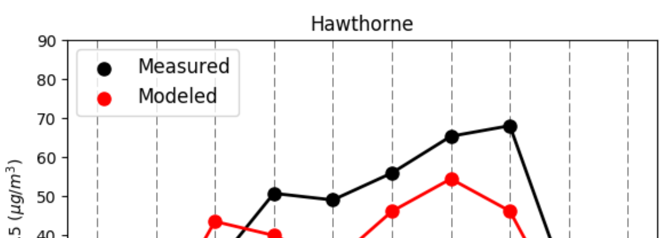

Figure 3.1.1: 24-hr $PM_{2.5}$ concentrations during January, 2011 episode for Hawthorne, Salt Lake County. Observed (black) vs. modeled (red).

Looking at observed speciated $PM_{2.5}$ mass from our Hawthorne CSN monitor (January 7), we see good agreement in nitrate (NO3) and ammonium (NH4) with our CAMx modeling results. The agreement between modeled and observed NO3 is a benefit from the ammonia injection. Simulated fine crustal matter (CM) and elemental carbon (EC) concentrations were a bit higher than observed. The overestimation in these two primary aerosols were the likely result of a high bias in MOVES 2014a (EC) and the re-suspended road dust calculation tool provided by the EPA (CM).

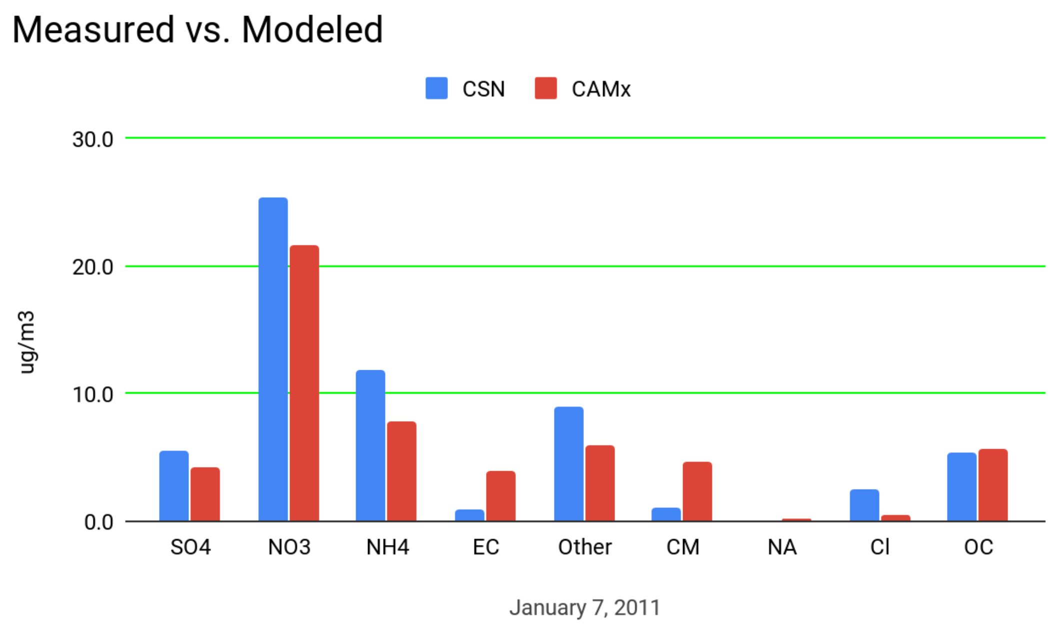

Figure 3.1.2: 24-hr speciated $PM_{2.5}$ mass ($\mu g/m^3$) for January 7, 2011. Blue (red) bars represent measured (modeled) mass for Hawthorne, Salt Lake County.

4.2. December 7-19, 2013

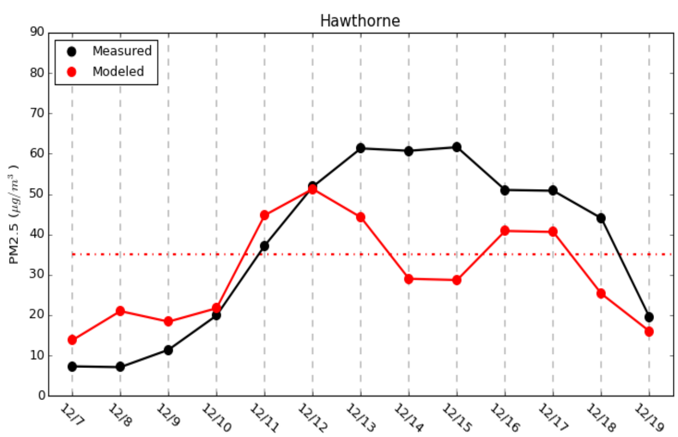

Figure 4.2.1: 24-hr $PM_{2.5}$ concentrations during December, 2013 episode for Hawthorne, Salt Lake County. Observed (black) vs. modeled (red).

At Hawthorne, modeled $PM_{2.5}$ was of a similar magnitude as observed. However, there was a strange bimodality in the modeled results not observed in measurements. While observations show peak $PM_{2.5}$ concentrations during December 13-15, CAMx is producing a local minima.

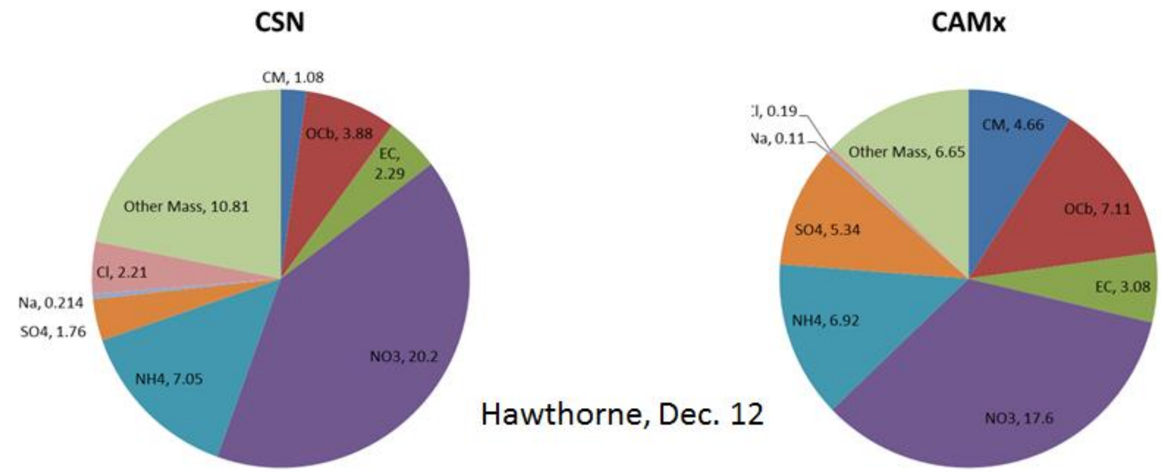

Figure 4.2.2: 24-hr speciated $PM_{2.5}$ mass ($\mu g/m^3$), December 12, 2013. Observed (left) vs. modeled (right). Hawthorne, Salt Lake County.

We had speciated AQS data for day (December 12) at the onset of the multi-day peak $PM_{2.5}$ period (December 12-16). NH4 and NO3 appear well simulated. As for January, 2011, modeled crustal matter is much higher than observed. Modeled SO4 was roughly 3 times higher than observed.

Overall, the speciation for December 12 appears reasonable. But, the use of the December, 2013 episode data may not be a good choice for attainment demonstration modeling. The anticorrelation between modeled and observed results during the peak $PM_{2.5}$ period is concerning.

4.3. February 1-16, 2016

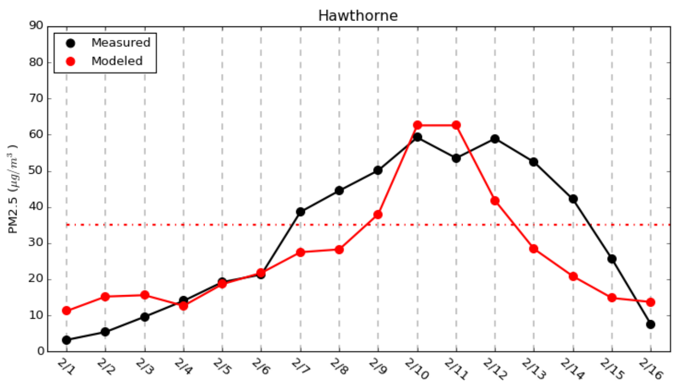

Figure 4.3.1: 24-hr $PM_{2.5}$ concentrations during February, 2016 episode for Hawthorne, Salt Lake County. Observed (black) vs. modeled (red).

Utah DAQ was able to simulate the peak $PM_{2.5}$ concentration levels seen in monitored observations at Hawthorne for February, 2016. At Hawthorne, modeled $PM_{2.5}$ tapered off rapidly during the latter part of the February episode (February 12-16).

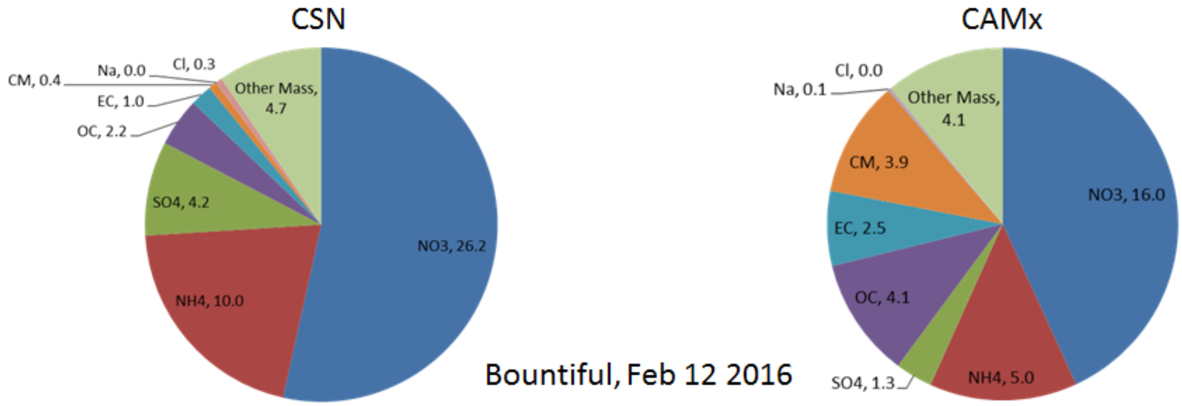

Figure 4.3.2: 24-hr speciated $PM_{2.5}$ mass (μg/m^3), February 12, 2016. Observed (top) vs. modeled (bottom). Bountiful, Davis County. Bountiful is used since Hawthorne measurements were unavailable.

For February 12, NO3 and NH4 performance was relatively poor compared to the other two episodes considered. Modeled organic carbon (OC) was twice as high than measured and SO4 was underrepresented by the model. The CAMx results do not quite reflect the high wintertime PM.25 composition we would expect during this period.

5. Conclusion

When we visually examine $PM_{2.5}$ model performance for all three episodes, it's clear that CAMx performed best when we used the January, 2011 WRF output. This is not too surprising since the University of Utah worked on calibrating the WRF model specifically to January, 2011 meteorological conditions. The University of Utah worked specifically on improving WRF performance for January, 2011 because this specific period coincided with the Persistent Cold Air Pool Study[4] (PCAPS), an exhaustive field campaign focused exclusively on the Salt Lake Valley.

The scatter plots below (figure 4.4.1) show simulated $PM_{2.5}$ against observed $PM_{2.5}$, measured at the Hawthorne Federal Reference Method (FRM) monitor. A linear regression fit is also shown. The relatively tight dispersion in (FRM, CAMx) points along the diagonal black line (x=y) for January, 2011 implies that model bias is low and temporal correlation is high relative to when using WRF output for the other two episodes.

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

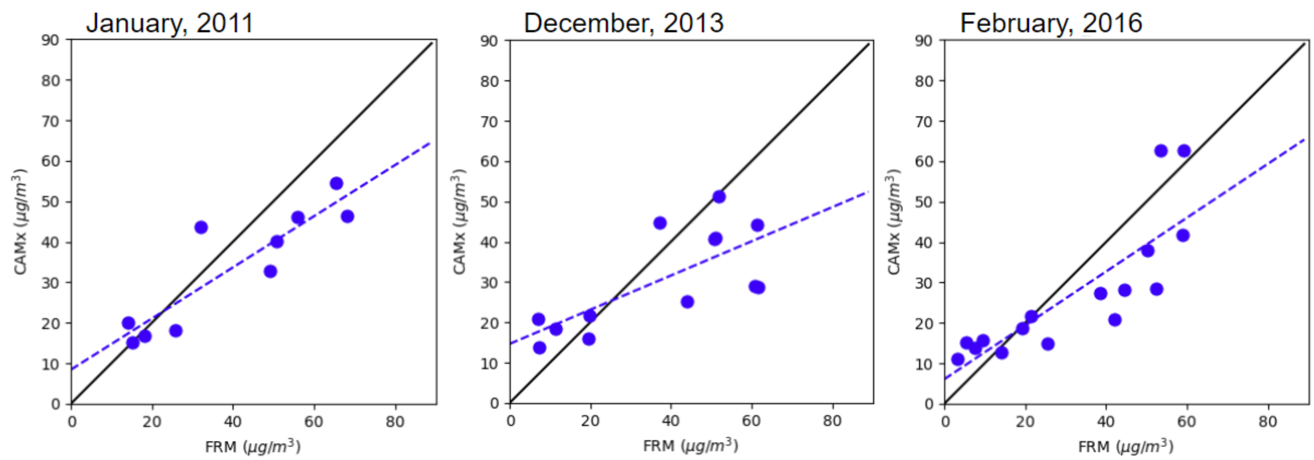

Figure 5.1: Modeled (vertical axis) versus measured (horizontal axis) 24-hour $PM_{2.5}$ for three meteorological episodes. Daily Results for Hawthorne are shown for a given simulated episode. Linear regression fits are shown for each simulated episode.

Table 5.1, below, shows three model performance metrics for each monitor and episode:

1. **Slope** (or Beta, β): These are the slopes of the linear regression fits (dashed lines) visually depicted above in figure 5.1. The slope is a measure of the difference between observed and measured values.
2. **R^2**, correlation of determination: R^2 is the square of the pearson correlation coefficient and as such, is a measure of temporal correlation.
3. **Mean error**: The mean error is defined as the average absolute difference between observed and modeled daily $PM_{2.5}$ concentrations. The mean error is a measure of model bias that avoids the spurious influence from temporal anticorrelation.

Episode Year	Monitor	Slope	R^2	Mean Error
2011	Hawthorne	0.63	80%	9.61
2013	Hawthorne	0.42	52%	12.42
2016	Hawthorne	0.67	68%	9.85

Table 5.1: List of model performance metrics for Hawthorne (Salt Lake County). Best metrics are listed in purple.

In our estimation, the January, 2011 WRF data led to better CAMx performance when compared with the other two episodes. Therefore, UDAQ selected the January, 2011 episode to conduct its modeled attainment demonstration.