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Improving Regional PM2.5 Modeling along Utah's Wasatch Front

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1. INTRODUCTION

It is well documented that Utah frequently exhibits large winter-time PM2.5 concentrations. Utah's winter-time exceedances of the 24-hour PM2.5 National Ambient Air Quality Standards (NAAQS) are attributed to strong temperature inversions. These temperature inversions can last several days during persistent high-pressure, low surface-wind conditions. In turn, low-level mixing layers trap fine particulate matter near the surface and create a public-health concern.

Utah's complex topography creates a unique challenge. Air quality models struggle to obtain adequate performance or accurately portray regional PM2.5 composition. During winter-time exceedances, particulate nitrates (PNO3) often represent the largest portion of PM2.5 mass, contributing more than organic carbon. To achieve adequate performance, past PM2.5 modeling required disabling the vertical advection scheme and adding additional ammonia.

To address the challenges of simulating PM2.5 along the Wasatch Front, the Utah Division of Air Quality (DAQ) has greatly advanced their photochemical modeling platform. Currently, we are using the Comprehensive Air Quality Model with Extensions (CAMx), version 6.30. This recent release of CAMx includes Utah DAQ-funded updates to the CB6 chemistry mechanism, snow-cover treatment, and surface model. We considerably increased the number of vertical layers (41) and horizontal grid resolution (1.33 km) of the modeling domain.

Finally, meteorological modeling inputs have greatly improved to better capture persistent near-surface air stability.

Here, we compare the differences between our current modeling approach and prior modeling efforts. We present results from our recent modeling of the January, 2011 Persistent Cold Air Pool Study (PCAPS) intensive field campaign. Subsequently, we demonstrate a marked improvement in simulating peak PM2.5 concentrations, PM2.5 composition, and temporal correlation with observations.

2. METEORLOGY MODELING

Utah DAQ contracted with the University of Utah to run meteorological simulations for three episodes. This presentation will focus on one of them: January 1st – January 11th, 2011. As explained in the introduction, this period coincides with an in-depth field campaign that measured a host of meteorological and air quality variables along the Wasatch Front.

The University of Utah improved winter-time WRF simulations in two key ways (Christopher Foster, M.S. Thesis). First, the WRF parameters, MAXALBEDO and SNUP, were adjusted to increase the maximum allowable surface albedo and increase snow cover.

Second, the National Land Cover Database (NLCD) 2011 land use data was modified using more recent satellite imagery to accurately depicted the Great Salt Lake's lower water levels in 2011 (see Figure 1).

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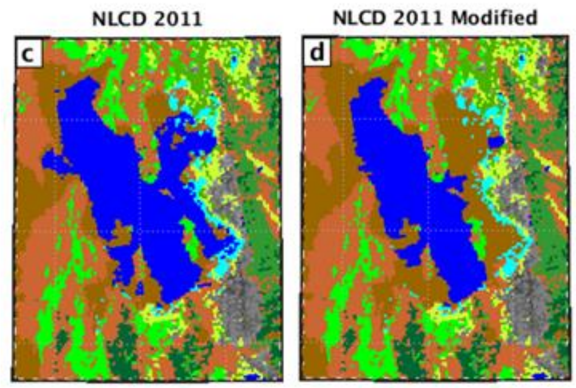

Fig. 1. Left panel shows original GSL. Right panel shows modified GSL with less water.

The result of these two WRF modifications greatly enhanced albedo to better match the high measurements recorded during the 2011 PCAPS campaign.

The January, 2011 episode was ideal to model since low wind speeds near the mixing layer height and a simple single-layer cloud structure were apparent through most of the episode. These episodic features are considered to be important for sustaining the lengthy temperature inversion period in WRF.

3. AIR QUALITY MODELING

3.1 Model Parameterization

Our photochemical modeling uses the most-recently released CAMx version 6.30. Some of the important options we use for our simulation include:

- Carbon Bond (CB6r3) gas-phase chemistry mechanism.
- CF aerosol chemistry mechanism
- Zhang 2003 dry deposition scheme
- Euler-Backward Iterative (EBI) numerical chemistry solver
- Piecewise Parabolic Method (PPM) horizontal advection solver
- Wet deposition turned on

3.2 Spatial Configuration

We use utilize two gridded domains at 4 km (coarse) and 1.33 km (fine) horizontal resolution. Both domains are situated in a two-way nested grid configuration. Rather than having only the coarse domain informing the fine domain, this two-way nested structure enables information to be propagated simultaneously between the two grids.

The coarse domain covers the entire state of Utah. The fine domain covers a smaller geographical region that encompasses Utah's three 24-hour PM2.5 non-attainment regions (See Figure 2)**.**

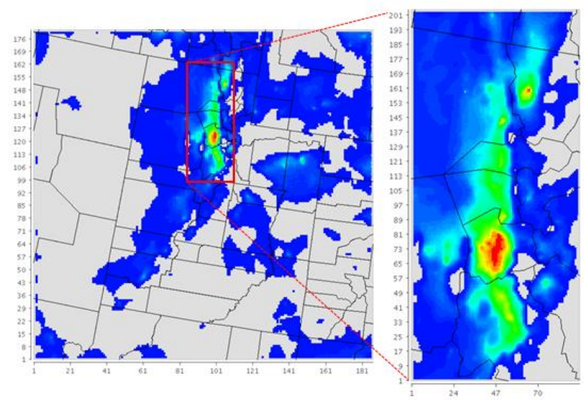

Fig. 2. 4 km (180 rows, 186 columns) grid with red-box outlining nested 1.33 km (201 rows, 90 columns).

3.3 Emissions Inputs

Anthropogenic emissions in our inventory were processed using the CMAS SMOKE 3.6.5 emissions model. Our 2011 stationary non-point inventory was created from back-casting 2014 National Emissions Inventory (NEI) estimates to 2011. Back-casting was conducted because the emission factors used in the 2014 NEI are considered better quality than what was used in the 2011 NEI. Our point source inventory estimates were taken from the 2011 NEI. Episode specific mobile emissions were created using the EPA's MOVES 2014a model.

Temporal profiles were used in SMOKE for portraying wintertime emission levels. VOC and primary PM2.5 speciation profiles were taken from the EPA's 2011v6 modeling platform. Primary PM2.5 profiles were translated to CF from AERO6 for CAMx use.

3.4 Modifications

Initial modeling runs resulted in underestimates of PNO3 when compared with STN measurements taken during days of high PM2.5 concentrations. To compensate, Utah DAQ made the following two adaptions to the CAMx source code:

1. Snow cover fraction for urban land use was set to 88%
2. Ozone deposition velocity was set near 0 m/s

Snow cover fraction was adjusted to closely reflect satellite observations of the Salt Lake Valley taken January 1st, 2011. This adjustment had the effect of increasing CAMx albedo to better reflect urban Salt Lake Valley observations.

Increased surface albedo coupled with making more ozone available for oxidation of NH3 and HNO3 increased PNO3 by nearly 10% of measured PM2.5 mass.

4. RESULTS

4.1 Model Performance

Figure 3, below, shows 24-hour PM2.5 modeled results versus FRM measurements at Hawthorne Elementary School (a controlling monitor for the Salt Lake nonattainment region).

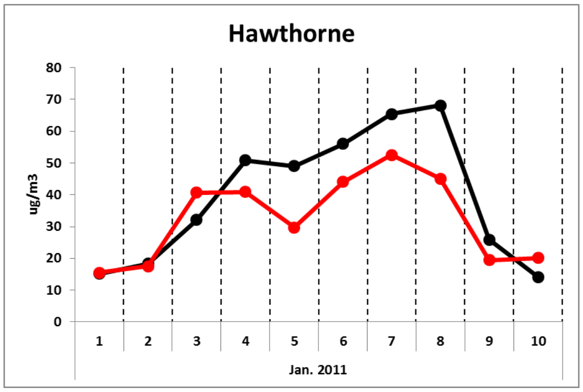

Fig. 3. Time series plot of measured (black) versus modeled (red) 24-hour average PM2.5 at Hawthorne Elementary (Salt Lake City), Jan. 1-10, 2011.

Temporal correlation between modeled estimates and observations is high during the episode. Day 5 of the modeling simulation suggests that WRF exaggerated air instability in the presence of a weak low-pressure system that entered the Salt Lake Valley at that time.

The modeled PM2.5 mass is also reasonable as several National Ambient Air Quality Standard (NAAQS) violations are successfully simulated. However, WRF failed to produce the mid-level clouds that appeared overnight on Day 3. Subsequently, the mixing height was likely underestimated in the model. The lower mixing height likely produced an overestimation of simulated PM2.5 on that particular day.

Initially, model results showed an overabundance of primary organic aerosols (POA). Utah DAQ applied the KVPATCH pre-processing utility (Ramboll-Environ) in order to raise the minimum value vertical diffusion coefficients are allowed in CAMx. This had the desired effect of reducing POA and produced a more realistic PM2.5 speciation profile from the model.

4.2 Comparison to prior performance

Past Utah DAQ air quality modeling was conducted using the CMAQ 4.7 air quality model with one 4 km domain. With this past platform, it was extremely challenging to build up PM2.5 concentrations without disabling the vertical advection scheme in CMAQ. Non-inventoried ammonia was also introduced into the model in order to help build ammonium nitrate.

A 42-day episode (consisting of four peak PM2.5 days) was simulated for prior State Implementation Plan (SIP) work. As shown below in Figure 4, model performance is poor with vertical advection enabled (red line).

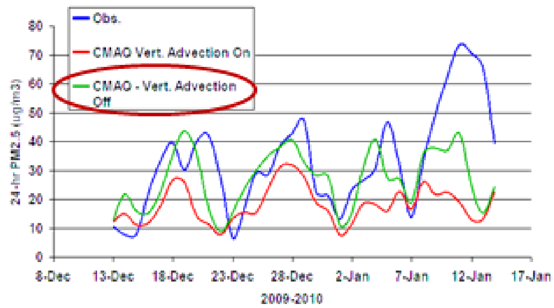

Fig. 4. Time series plot of older 24-hour PM2.5 modeling results for Salt Lake City, Dec. 13, 2009 – Jan. 14, 2010.

5. CONCLUSION

The results presented here reflect a significant step forward in PM2.5 modeling performance for the Wasatch Front region. However, work on improving model performance is still ongoing at Utah DAQ.

Given the air quality model refinements described here, Utah's air quality modeling will likely be more helpful in informing policy decisions. At the same time, Utah's current progress should also increase confidence in future attainment projections of daily PM2.5.