Scope of Work

Improve Air Quality Modeling for the Wasatch Front & Cache Valley Winter Air Pollution Episodes

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Investigators: John Horel and Erik Crosman

Department of Atmospheric Sciences

University of Utah

Submitted to Patrick Barickman

Manager, Technical Analysis

Utah Division of Air Quality

1) Project Background

The metropolitan Wasatch Front area along the west slopes of the Wasatch Mountains and Cache Valley include 85% of Utah's population. As the state's population doubles to over 5 million residents in the next several decades, virtually all of the population growth will occur in this region, which has experienced poor wintertime air quality in recent years. Cache, Box Elder, Weber, Davis, Tooele, Salt Lake, and Utah counties are classified as not in attainment for $PM_{2.5}$ relative to the current EPA National Ambient Air Quality Standard (NAAQS).

The proposed research builds upon recent observational and modeling studies of winter air pollution episodes in the Salt Lake Valley. The National Science Foundation supported the Persistent Cold-Air Pool Study (PCAPS) from 2010-2014, which was a collaborative research project with Principal Investigators C. D. Whiteman and J. D. Horel from the University of Utah and Sharon Zhong from Michigan State University. A description of the project and key results are found in peer-reviewed papers by Lareau et al. (2013), Whiteman et al. (2014), and Lareau and Horel (2014a,b). The proposed research also leverages observational and modeling studies conducted with funding from the Utah Division of Air Quality (DAQ) for episodes of high winter ozone concentrations in the Uintah Basin (Neemann et al. 2014).

As summarized by Whiteman et al. (2014), atmospheric particulate concentrations in the Salt Lake Valley have decreased over the last 40 years as air quality regulations have taken effect. Exceedances of the 2006 federal 24-h-average NAAQS for fine particulates in winter occur during multi-day episodes associated with high-pressure ridges aloft. The 35 µg m-3 standard is exceeded ~18 days per winter in the Salt Lake Valley. The particulate concentrations in the Salt Lake Valley tend to build up rather uniformly with time during these multi-day periods during which cold polluted air is trapped beneath the ridging aloft (Malek et al. 2006, Gillies et al. 2010, Whiteman et al. 2014). These polluted cold-air pools are affected by atmospheric processes on a range of scales (Lareau et al. 2013). Synoptic-scale processes control the development of the trapping stable layer aloft while terrain-flow interactions affect pollutant concentrations within the boundary layer and near the surface (Lareau and Horel 2014a).

Modeling the complex meteorological features associated with these cold-air pools is difficult and is recognized as one of the greatest challenges facing boundary layer meteorology (Holtslag et al. 2014). DAQ staff have used the Community Multiscale Air Quality (CMAQ) model, driven with meteorology from the Weather Research and Forecasting (WRF) model, to investigate ways to bring $PM_{2.5}$ levels in nonattainment areas of northern Utah in compliance with the NAAQS. DAQ staff have undertaken hundreds of model runs in collaboration with EPA modelers to evaluate configurations of the WRF model and CMAQ to develop the State Implementation Plan (SIP) for PM2.5, recently submitted to the EPA (DAQ 2013). However, from DAQ's experience, their combined WRF/CMAQ runs required unphysical modifications to simulate the buildup of pollutants during wintertime cold-air pool events. Present versions of the WRF model tend to develop mixing heights that are too deep and surface layers that are too warm during wintertime pollution events, a common problem attributable in part to the limitations of the commonly-used parameterization schemes for stable boundary layers (Holtslag et al. 2014).

DAQ staff have identified that the most critical processes requiring WRF model improvements include:

a) vertical temperature profile and stability within the planetary boundary layer that controls the buildup of pollution and its precursors
b) influence of snow cover/depth on surface temperature and stability
c) diurnal wind flows (slope and valley flows) common during high PM2.5 episodes.

Similarly, common themes emerging out of our PCAPS and Uintah modeling experiences are the need to:

a) have accurate large-scale initial and lateral boundary conditions that define the synoptic evolution of the cold-air pools
b) view the Wasatch Front and Cache Valley air pollution environment in a broader context that encompasses the entire Great Salt Lake Basin
c) specify the lower boundary state well, i.e., the underlying land, water, snow and soil surface conditions (Lareau et al. 2013, Lu and Zhong 2014, Neemann et al. 2014)
d) simulate atmospheric flows at higher resolution (≤~1 km) than that (~4 km) used by DAQ modelers previously for SIP applications.

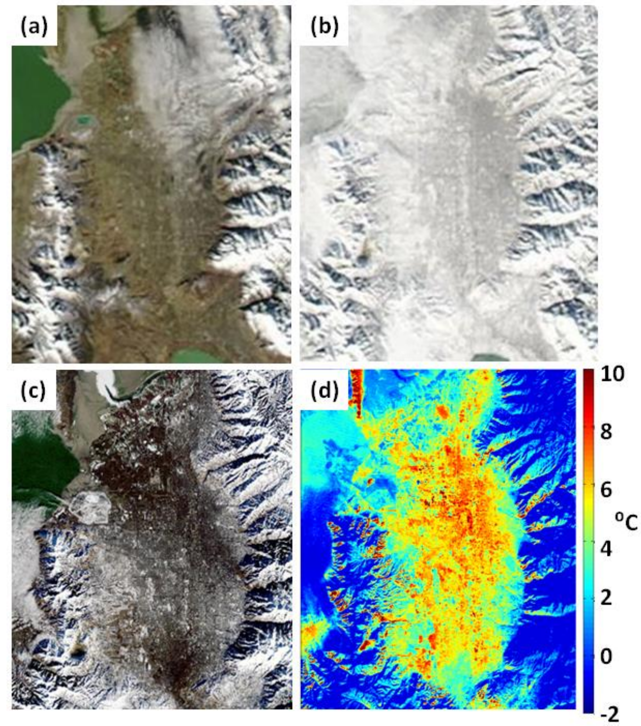

Fig. 1 a) Snow free period in the Salt Lake Valley (MODIS true color image 2040 UTC 12 Dec 2010), **b)** Snow-covered period (MODIS on 1900 UTC 6 January 2011), **c)** Partially snow covered over higher elevations in the Valley (Landsat 5 TM True color 1758 UTC 27 Jan 2011 from bands 1-4 at ~30 m resolution), **d)** Skin temperature for the same time as (c) **(**Landsat 5 TM skin temperature (^{0}C) derived from band 6 (10.4-12.5 μm) at ~120 m resolution).

For example, Figure 1 illustrates with MODIS and Landsat imagery the variations in surface state that are common along the Wasatch Front during winter—i.e., snow free (Fig. 1a), snow covered (Fig. 1b), or partial snow cover (Fig. 1c). In addition, the time-height sections of potential temperature at a location near the center of the Salt Lake Valley from a Large-Eddy Simulation (200 m horizontal resolution with 72 vertical levels) are compared in Fig. 2 to the observed potential temperature profiles during the period of diminishing snow cover (Fig. 1c). While the simulation misses some details related to the depth of the cold-air pool beneath the stable layer, our experience and that of other researchers suggests simulations at 1 km or less are necessary to simulate more accurately these episodes of winter poor air quality.

The core objectives of this project are:

1. **Determine appropriate atmospheric model configurations including treatment of the underlying surface to simulate wintertime cold pool events along the Wasatch Front and in the Cache Valley that lead to high PM2.5 pollution**

2. **Collaborate with Utah DAQ staff to identify and simulate selected cold-air pool episodes to be used in PM2.5 SIP development**

2) Task Descriptions

a. Selection of Cold-Air Pool Episodes

Our modeling activities currently underway for cold-air pool cases during the 2010-2011 PCAPS field campaign as well as the experiences of DAQ modelers indicate that there are no "off the shelf" modeling configurations that work presently for all situations. For the development of the prior SIP for PM2.5, an approximately month-long period during the 2009-2010 winter was used to evaluate the WRF model's performance and a number of deficiencies were identified as mentioned earlier based on numerous model configurations.

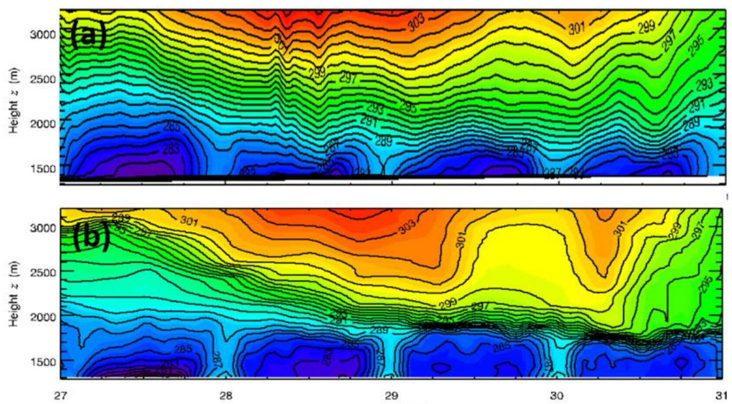

Fig. 2. Time height section of potential temperature in the center of the Salt Lake Valley from 27-31 January 2011 for: **a)** Large Eddy Simulation and **b)** observed. Particulates become trapped beneath the strong stable layer within the cold-air pool (blue shading).

Selection of appropriate episodes to assess model performance is the first step to be completed in close coordination with DAQ staff. Testing for 1-2 cases during the 2010-2011 winter will likely be undertaken, due to the greater availability of validating data and our familiarity with the high air pollution episodes during that winter. However, that winter is not likely an appropriate one for future SIPs. In addition, there are now more validation assets available to assess conditions during more recent winters including the DAQ radiometer, several ceilometers deployed in the Salt Lake Valley (and one to be available soon in the Cache Valley), two sodars in the Salt Lake Valley as well as additional surface meteorological stations. Hence, cases from the 2013-2014 and 2014-2015 winters are likely to be particularly useful.

Parameter	Base Configuration
Microphysics	Thompson
Short and long wave Radiation	RRTMG
Boundary Layer	Mellor-Yamada-Janjic (MYJ)
Cumulus	Kain-Fritsch (outer domain)

Table 1. WRF parameterizations

b. Improved specification of model configuration, parameterizations, and underlying surface conditions

We have spent considerable time testing different suites of physical parameterizations (Table 1) necessary to capture winter cold-air pools, and we expect to continue to test whether those remain appropriate. In particular, the performance of several newly implemented WRF PBL and microphysics parameterization schemes in persistent cold-air pool situations that remain most difficult to model (cloudy or partial-mix-out) will be analyzed. The impact of surface state (snow cover) on cold-air pool development has been demonstrated (Neemann et al. 2014). We will extend this work to test the sensitivity of model results to the standard available land surface categorization option currently supported by WRF: The 33 category National Land Cover Database 2006, the 24 category USGS 2000, and the most recently available 20 category MODIS product. Our goal is to develop and transfer modeling capabilities to DAQ modelers that do not require multiple sets of model configurations. The telescoping nested model domains rely on a 4km base resolution as shown in Fig. 3. The 4 km resolution is used most frequently by DAQ based on available emission inventories. The 0.44 km grid will likely be run without a boundary layer parameterization used, i.e., configured as a Large-Eddy Simulation. Short duration simulations at resolutions down to ~150 m will be tested for the Salt Lake and Cache Valleys to further evaluate the sensitivity to horizontal resolution. Similar testing on sensitivity to vertical grid spacing will be conducted as well. Our intention initially is to not rely on analysis or observation nudging, which frees up observations for validating the model performance.

c. Perform and Evaluate Model Simulations of Cold-Air Pool Episodes

We will perform high resolution atmospheric nested model simulations with domains that cover the Wasatch Front and Cache Valley (Fig. 3). As discussed above, case selection will be made in coordination with DAQ staff focusing on wintertime cold pool events that lead to high PM2.5 pollution. Model simulations with horizontal resolutions of ~1km or less are needed to best represent the structure and stability of the lower boundary of the atmosphere.

The research team will evaluate the model performance identifying the strengths and weaknesses as a function of the case situation, e.g., snow/no snow in valley floors; none or extensive low- or mid-level clouds, quiescent or impinging synoptic or mesoscale flows. Of particular interest will be to evaluate mountain-valley circulations along the Wasatch Front and Cache Valley, which is necessary to diagnose the transport of PM2.5 and its precursors.

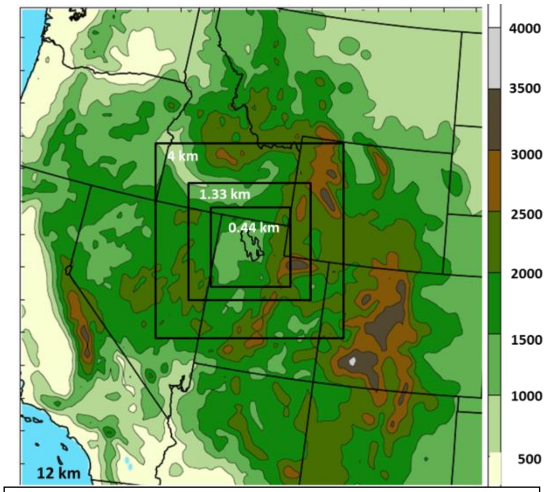

Fig. 3. Terrain elevation (m) in the Western U.S. with approximate 12, 4, 1.3, and 0.44 km domains.

We will rely on the computational resources available to us on compute servers available in our group as well as request compute cycles on the shared clusters in the University of Utah's Center for High Performance Computing.

d. Upscale sub 4-km model output

Based on the degree to which simulations at resolutions higher than 4 km improve on boundary layer structures and depiction of horizontal and vertical motions relative to those at 4 km, techniques will be tested and implemented to upscale model output for use in photochemical models at 4 km resolution to be consistent with the needs for SIP modeling. Loss in the fidelity of the horizontal and vertical motions or vertical profiles of temperature and moisture simulated at the high resolutions will be assessed.

3) Deliverables

Specific deliverables to be provided during and upon completion of this project are:

1. Evaluation of possible case studies and periods that are appropriate for future SIP modeling studies
2. Informal updates with DAQ staff on our results on appropriate model configurations and parameterizations as well as the degree to which improved specification of the underlying surface state improves model performance
3. Output from all case studies provided in a format convenient for use in photochemical models used by DAQ modelers (e.g., CMAQ)
4. Validating data sets archived in formats convenient for additional model testing and evaluations

5. All model configuration files and modifications to model codes stored in a repository for use by DAQ staff and other researchers

6. Final report detailing model set-up and configuration and model performance of modeled meteorological features of cold-pool pollution events (e.g., snow cover, boundary layer structure, wind flows).

4) Schedule and Cost

The University of Utah researchers will be in frequent communication with DAQ staff throughout the project. We intend to be available for the technical stakeholder and communication strategy meetings. Specific project milestones are:

- October 15. Complete identification of possible prior winter case studies with DAQ staff;
- December 15. Complete testing of WRF sensitivity to land surface schemes (USGS, NLCD, MODIS) and snow cover options.
- January 15. Graduate student attends CMAQ workshop to become familiar with atmospheric modeling needs required for CMAQ during late October.
- March 15. Complete testing of WRF sensitivity to PBL and cloud microphysics parameterization schemes
- April 15. Assess whether any 2014-2015 air pollution events should be examined.
- July 15. Complete testing of large-eddy simulations
- October 15. Complete summary of types of cold air pools from modeling perspective and appropriate WRF model setup for the different types
- January 15. Submit final report

Budget 15 July 2014-14 January 2016

Postdoctoral Researcher Erik Crosman (6 months)	$34,105
Graduate student (18 months)	$35,689
Fringe Benefits (37% for Postdoctoral researcher; 14% for student)	$17,615
Travel- Domestic (graduate student attend CMAQ training)	$3,500
Total Direct	**$90,909**
Direct Costs for F&A Calculation	$90,909
Indirect (F&A) Cost	**$9,091**
Grand Total	**$100,000**

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