$PM_{2.5}$ State Implementation Plan

Modeling Protocol

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1. Overview of Modeling and Analysis Project

1.1 Management Structure

The draft development of this document is being led by the Technical Analysis Group of the Utah Division of Air Quality (UDAQ). A committee has been formed to make decisions about the technical methods that will be used for this study. The members of this group represent the following agencies:

- State of Utah
- State of Idaho
- EPA Region 8
- EPA Region 10

Through a series of periodic telephone conference calls all of the technical proposals and decisions regarding the methods used in this study will be discussed and agreed to by the members of this committee. When the substantive elements of this document are agreed to by all of the committee members the protocol will be considered to be in its final draft form.

1.2 Technical Committees and Participating Organizations

Modeling: The UDAQ modeling team performs meteorological, chemistry, and emissions modeling for the $PM_{2.5}$ SIP. The team interfaces with EPA Region 8 and 10 as well as the State of Idaho.

Emissions Inventory: The UDAQ emissions inventory group collects inventories. The group produces episodic inventories for SIP modeling, projects inventories to future years, and develops the Inventory Preparation Plan. The inventory group interfaces with EPA Region 8, EPA Region 10, and coordinates with the State of Idaho.

Mobile Sub-Committee: UDAQ in conjunction with the Metropolitan Planning Organizations of the Wasatch Front and Cache Valley work together to implement the new EPA MOVES mobile emissions model and to create episodic emissions inventories for SIP modeling. The sub-committee interfaces with EPA Region 8, EPA Region 10, and coordinates with the State of Idaho.

1.3 Schedule for Completion of Attainment Demonstration

Table 1.1 shows the general time line for completion of the major modeling milestones in developing the base case and future year modeling episodes.

Table 1.1 Milestones for major technical tasks

	2009		2010				2011				2012			
Task Description	q3	q4	q1	q2	q3	q4	q1	q2	q3	q4	q1	q2	q3	q4
Model Validation and Performance Evaluation														
met characterization														
Emissions Inventory (baseline)														
Inv. Prep. Plan														
mobile sources														
area sources														
point sources														
2nd iteration (final modeling inventories)														
Future Year Model Runs														
Emissions Inventory (projections)														
mobile sources														
area sources														
point sources														
Control Strategy Development														
list of options														
test using AQ model														
final selections														
Final Modeling Iterations														

1.4 Description of Conceptual Model

1.4.1 Conceptual Model Introduction

In 2009, EPA designated 3 regions in northern Utah as $PM_{2.5}$ non-attainment areas due to high 24-hour average $PM_{2.5}$ concentrations that occur during winter-time stagnation episodes in Utah valleys. The "Wasatch Front" is included in the Salt Lake City and Utah County non-attainment areas. Parts of Cache County, Utah and Franklin County Idaho are included in the Logan non-attainment area (see Figure 1.1). Traditionally, the term Wasatch Front has been used to describe the most densely populated area of the state. This is comprised of four counties that lie on a north-south axis along the west slope of the Wasatch mountain range and includes Weber, Davis, Salt Lake, and Utah counties. Portions of Tooele and Box Elder counties are also included in EPA's designation of the Salt Lake City non-attainment area. The meteorological conditions and chemical processes that lead to elevated winter-time $PM_{2.5}$ in Utah occur in very few locations in

the United States. The combination of the following factors make Utah's $PM_{2.5}$ problem both unique and difficult to model:

1) Mountainous topography.
2) High density of urban emissions sources.
3) Ridge dominated weather in SW United States.
4) $PM_{2.5}$ dominated by secondary chemistry.
5) High density of agricultural ammonia emissions sources near the urban area.

The situation that Utah faces is unique to the United States and presents significant meteorological and chemistry modeling challenges.

In addition to stagnation related 24-hour average exceedences, Utah experiences $PM_{2.5}$ exceedances caused by occasional high wind events during the spring and fall. As of August, 2010, UDAQ and EPA have not yet determined the most appropriate method to analyze these events in the context of the modeled attainment test. Language in the Clean Air Act seems to require the inclusion of PM concentrations measured during dust storms in the calculation of the design values for the model attainment test. If dust storm $PM_{2.5}$ data is included in the calculation of the design values it will increase the design value at several locations. The use of CMAQ with a modeled attainment test will be specifically tied to a winter inversion period. Photochemical grid models such as CMAQ perform poorly for wind blown dust events, so alternate modeling approaches would be required to evaluate the dust component for high wind events when wind blown dust is the primary component of $PM_{2.5}$.

When these issues are resolved, this protocol will be updated with an addendum to incorporate the technical approach to be used to assess wind-blown dust events for the Utah $PM_{2.5}$ SIP.

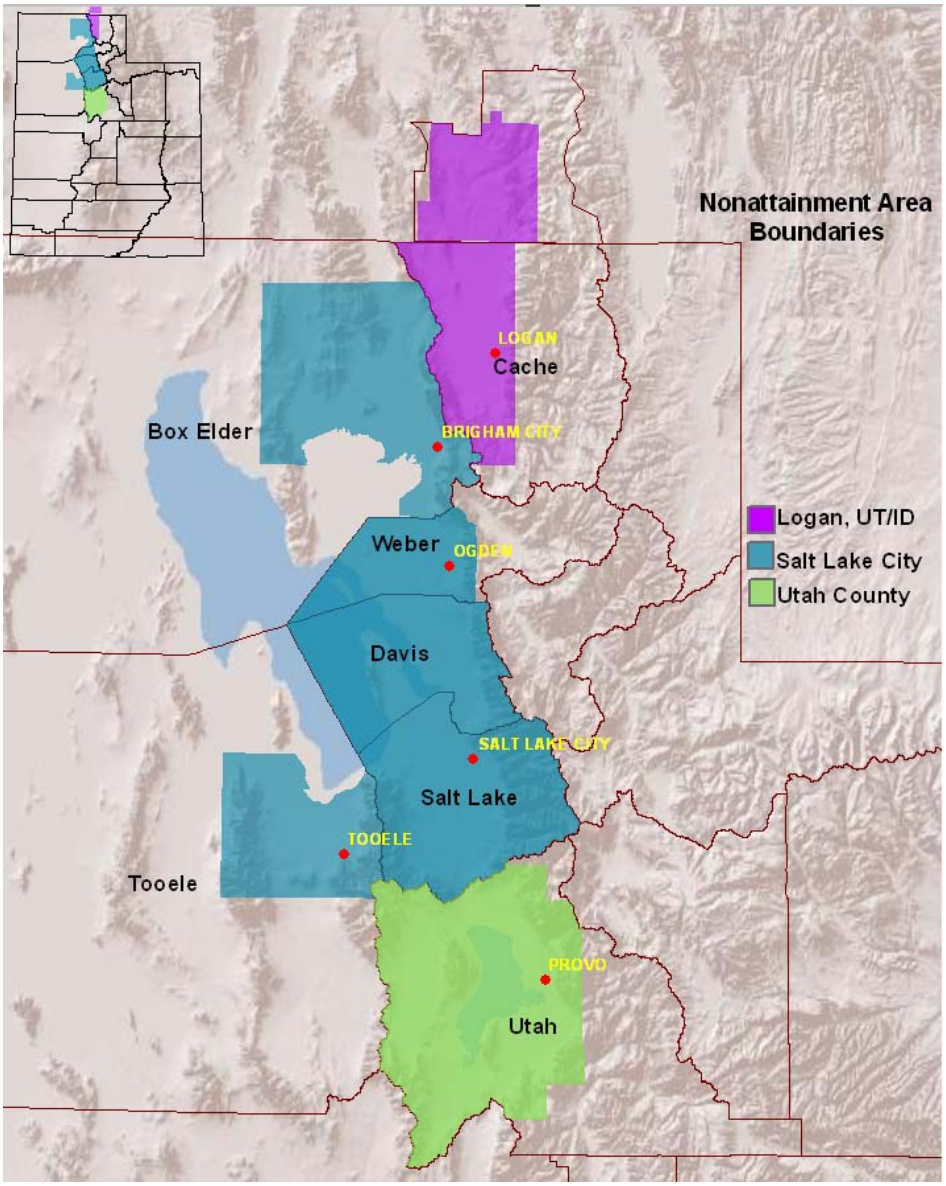

Figure 1.1 Utah $PM_{2.5}$ non-attainment areas

1.4.2 $PM_{2.5}$ Meteorology

While Utah's problem is unique the conceptual picture of the conditions that lead to elevated $PM_{2.5}$ is simple (Malek 2006). Utah's non-attainment areas sit in valley/basin bottoms which are known as Utah Lake Basin, Great Salt Lake Basin, and the Bear River Basin. During the winter-time, periodic ridges of high pressure park themselves over the Intermountain region and bring clear skies and quiescent weather. The presence of snow cover and weak insolation quickly allow temperature inversions to develop in basin bottoms. Without significant synoptic scale forcing mechanisms these nascent temperature inversions are not scoured out and stable cold pools can develop and strengthen as a result of the heat deficit present in the basin (Whiteman 1999) (Figure 1.2).

Emission sources within the stable cold pool provide the precursor emissions to form secondary $PM_{2.5}$ which accounts for over 75% of the total $PM_{2.5}$. Regional $PM_{2.5}$ represents only a fraction of the total $PM_{2.5}$ because transport winds are essentially non-existent in the regions dominated by the ridge.

Figure 1.2 Cold pool in Bear River (Cache) Valley

1.4.3 $PM_{2.5}$ Components

Utah's winter-time cold pool $PM_{2.5}$ in all 3 non-attainment areas is dominated by secondarily formed particulate. All winter-time cold pool speciated $PM_{2.5}$ data that UDAQ has collected supports this statement. The $PM_{2.5}$ is dominated by ammonium nitrate at all locations and includes significant portions of organic carbon. Table 1.2 summarizes UDAQ's speciated data that has been collected during the last 10 years.

The first 3 rows of Table 1.2 contain speciation statistics from the 3 longer term Speciation Network (STN) sites located along the Wasatch Front. The Bountiful and Lindon STN sites collect data on a 1 in 6 day schedule while the Hawthorne site collects data on a 1 in 3 day schedule. The statistics for these 3 STN sites reflects only days when the 24-hour average PM2.5 was >= 35 ug/m3. The fourth row of Table 1.2 provides data from a newly installed STN site in Logan. The statistics for this site reflect the 4 highest PM2.5 24-hour average concentrations that have been collected to date.

Rows 5, 6, and 7 of Table 1.2 show speciated data sets that were collected in the Cache Valley, including Logan, during the winter of 2004. These special study data sets from TEOM speciation, Mini_Vol speciation (Martin 2006), and real-time mass spectrometer speciation (Silva 2007) corroborate the newly acquired data from the Logan STN site and create a robust speciated data set for Logan and the Cache Valley.

Station	County	Monitor & Analysis Type	Year	Number Samples	Median PM2.5 ug/m3	Median PM1.0 ug/m3	% Ammonium Nitrate	% Ammonium Sulphate	% Organic Carbon	% Elemental Carbon
Bountiful	Davis	STN	Nov 2001+	18	44	NA	65%	7%	16%	3%
Hawthorne (Salt Lake City)	Salt Lake	STN	Feb 2000+	62	44	NA	56%	6%	21%	4%
Lindon	Utah	STN	Jun 2001+	22	50	NA	62%	3%	15%	2%
Logan	Cache	STN	Feb 2010+	4	28	NA	56%	3%	14%	4%
Logan	Cache	FRM	Jan-Feb 2004	20	92	NA	64%	6%	13%	1%
Cache Valley Rural*	Cache	Mini-Vol	Jan 2004	12	105	NA	65%	6%	NA	NA
Logan (USU)	Cache	Mass Spectrometer	Jan-Mar 2004	Continuous	NA	Up to 120	60-80%	~6%	15-20%	1-3%

*Hyrum, Newton, Preston, Amalga, Cornish, Franklin, Mendon, Richmond, Smithfield, USU

Table 1.2 Average $PM_{2.5}$ 24-hour average speciation for 2000-2009

Speciation profiles obtained from each location and each instrument are consistent with each other in that ammonium nitrate dominates the PM2.5 speciation. Furthermore, the data shows that speciation in the Cache Valley is similar to that along the Wasatch Front. The somewhat lower percentage of ammonium nitrate obtained from the Logan STN is likely the result of lower total PM2.5 concentrations. Only 1 of the 4 speciated observations was above the NAAQS, therefore, the median 24-hour PM2.5 concentration was only 28.4 ug/m3. A statistical analysis of Wasatch Front speciated data shows that the percentage of ammonium nitrate increases as total PM2.5 concentrations increase. The Logan finding is consistent with this Wasatch Front analysis.

The take away message is that $PM_{2.5}$ in Utah's non-attainment areas are dominated by ammonium nitrate and organic carbon. The data indicates that ammonium nitrate accounts for greater than half of observed $PM_{2.5}$ and can exceed 80% of the total $PM_{2.5}$ during the very highest $PM_{2.5}$ episodes. Organic carbon accounts for 15-20% of total PM2.5.

1.4.4 $PM_{2.5}$ Precursor Emissions

Emission inventories continue to be calculated, as they have in the past, using the most current models and emission factors. Mobile emissions will be calculated using the most recent EPA mobile model called MOVES.

As mentioned later in Section 1.5.2, violations of the NAAQS occur most often during stagnant, winter-time inversions and involve the production of secondary aerosols. Figures 1.3 and 1.4 show emission inventories for the non-attainment counties of the Wasatch Front and Cache County during a typical winter day. Pollutants shown are those most commonly involved in the formation of secondary particulates as well as the inventory of primary $PM_{2.5}$. Figure 1.5 is a view of just Salt Lake County and shows a further breakout of some of the major contributing categories to each of these pollutants.

Other than normal growth in population and commercial activity there are no significant changes in the nature of pollutants coming into the airshed over the past five to ten years.

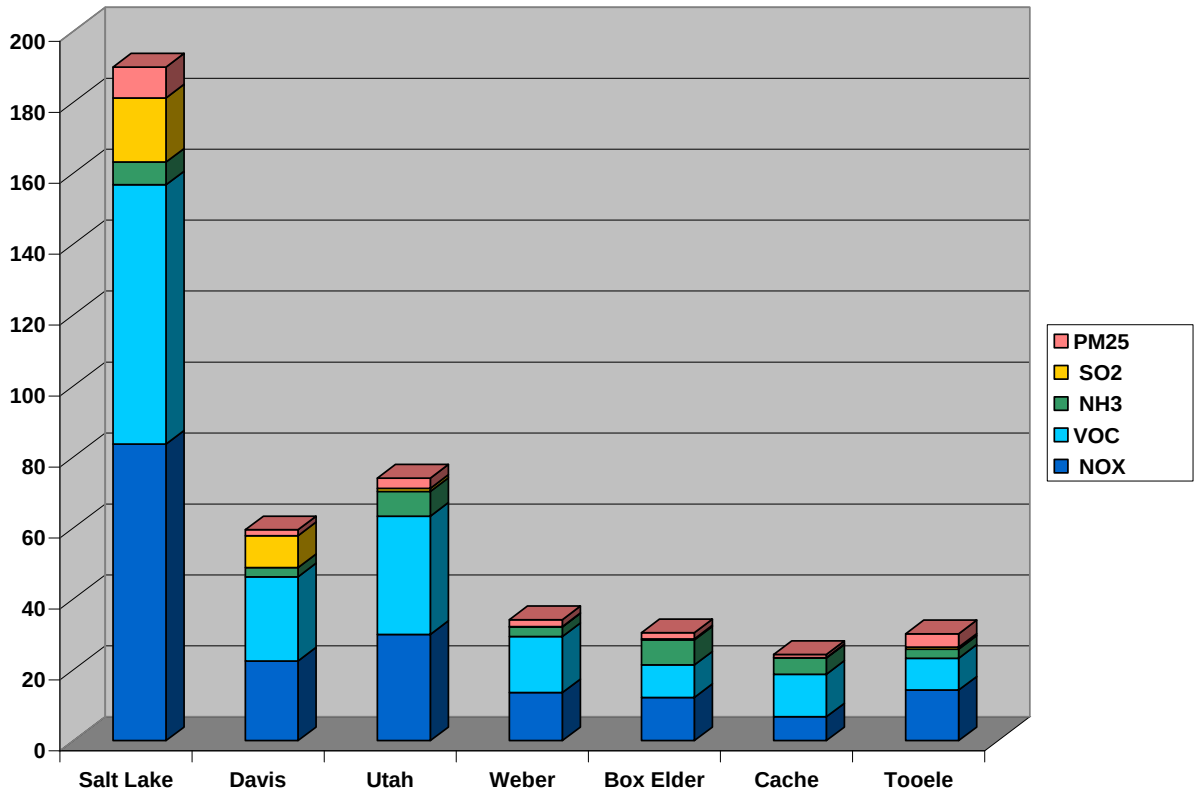

Figure 1.3 Sum of all emissions in tons/day for February 2008

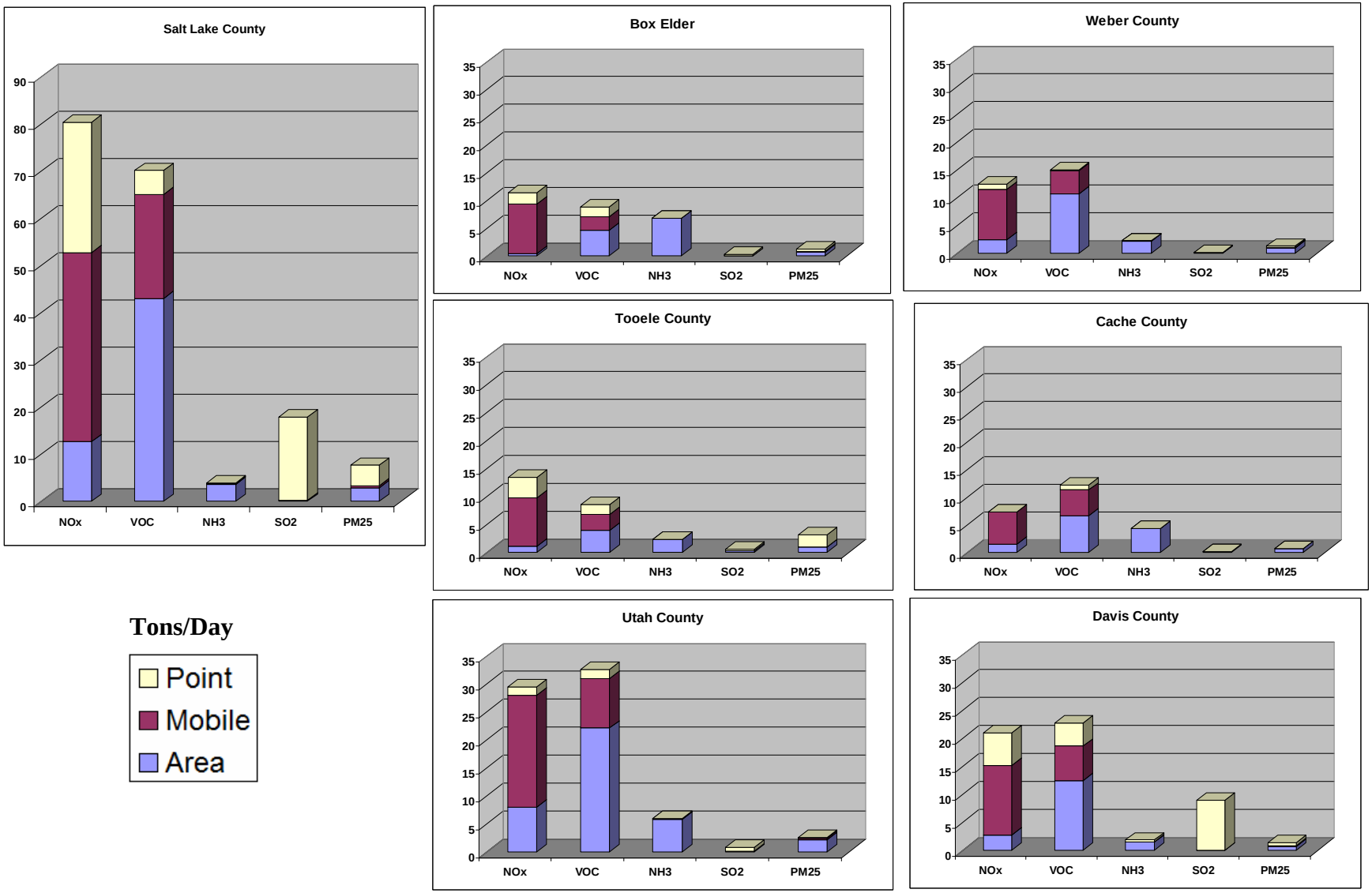

Figure 1.4 County emissions by type for February 2008

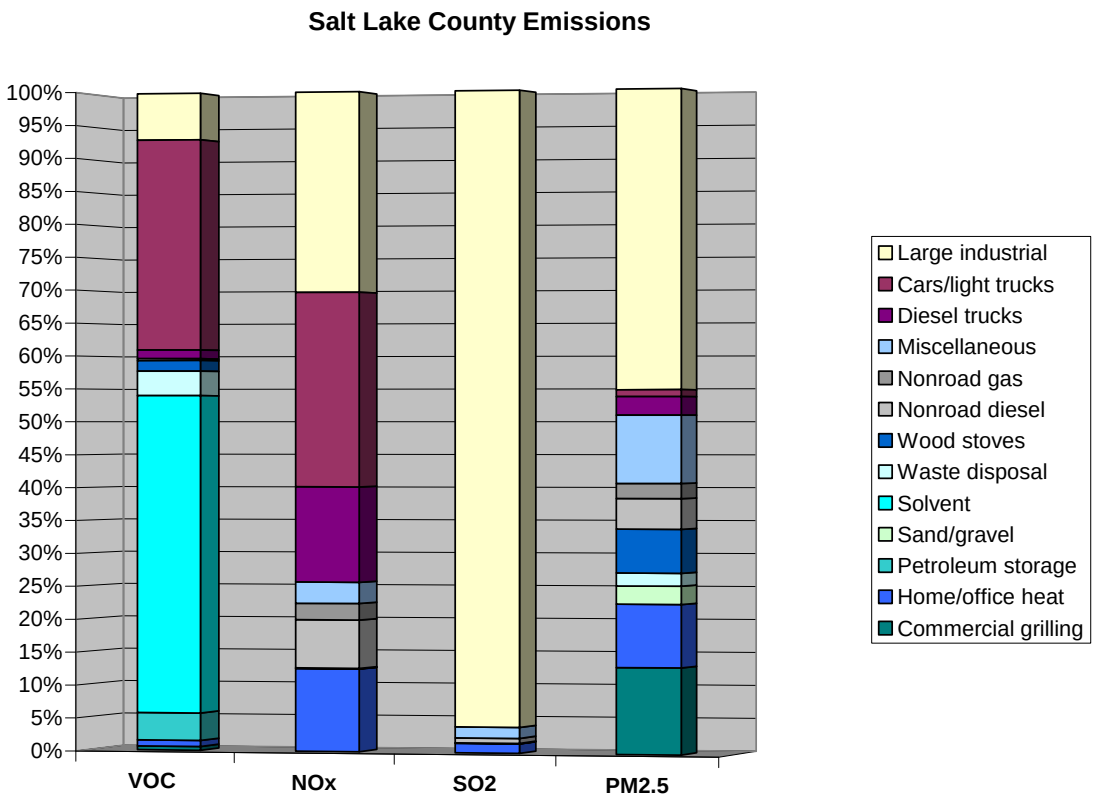

Figure 1.5 Major components of the inventory for Salt Lake County

1.4.5 $PM_{2.5}$ Spatial Patterns

The basin cold pools are regional in scale and dominate the formation and build-up of $PM_{2.5}$ at all of Utah's $PM_{2.5}$ monitoring locations. Localized terrain driven mesoscale weather features impact $PM_{2.5}$ concentration dynamics from location to location, however, these features are very hard to identify and model. The Utah Division of Air Quality has not measured sharp 24 hour average $PM_{2.5}$ concentration gradients anywhere in the non-attainments areas. Instead, concentrations gradually tail off as the distance from urban emission cores increase. Occasionally, sharp gradients do exist on a sub-24 hour time scale when a transient meteorological feature scours or partially scours one basin, but not another. This phenomenon has been observed when comparing the smaller Cache Valley to the larger Salt Lake Valley.

1.4.6 $PM_{2.5}$ Chemistry

The key questions with regards to Utah's $PM_{2.5}$ chemistry relates to the formation of ammonium nitrate are as follows:

1) Is the atmosphere ammonia (NH_3) limited?
2) Is it nitric acid (HNO_3) limited?

3) What is the primary pathway for HNO_3 formation?

Question 1:
At almost all times NH_3 is in excess from Cache County south to Salt Lake County. Figure 1.6 below illustrates excess NH_3 at Hawthorne during a January 2009 cold pool episode that led to hourly $PM_{2.5}$ concentrations in excess of 100 ug/m^3. NH_3 is present at all times. In the Cache Valley, investigations by Dr. Randy Martin from Utah State University show that NH_3 is almost never limited during the winter (see Figures 1.6 and 1.7, and Martin, 2006).

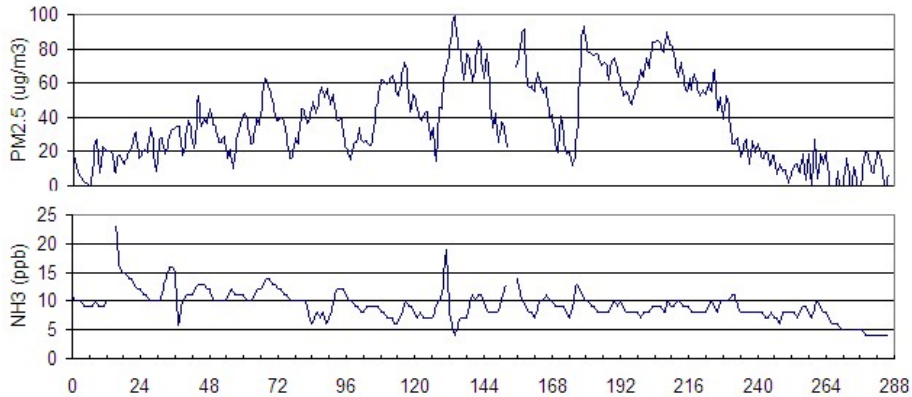

Figure 1.6 Hourly $PM_{2.5}$ and NH_3 at Hawthorne during January 2009

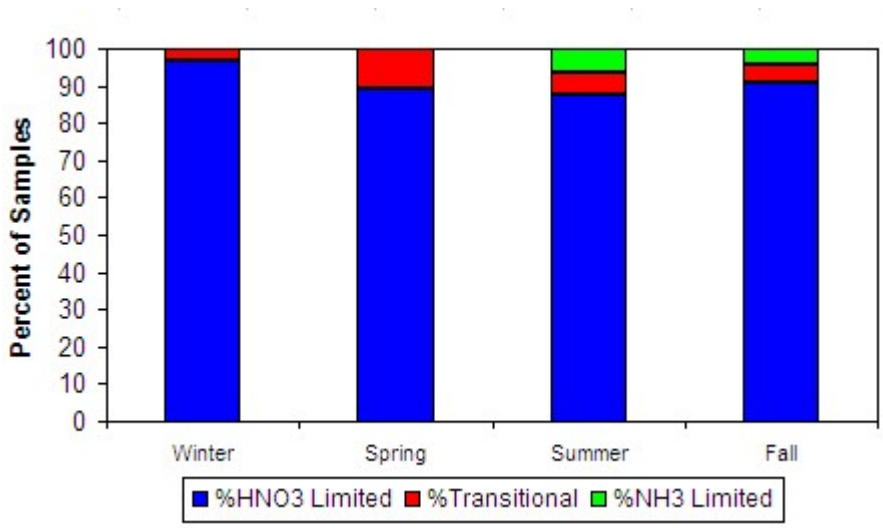

Figure 1.7 Percent of Logan, UT aerosol samples that are either limited by either HNO3- or NH3- (from Martin, 2006).

Questions 2 & 3:

Because ambient NH_3 data shows that NH_3 is almost always in excess and NO_x is plentiful, both the Wasatch Front and the Cache Valley are limited with respect to HNO_3 formation. HNO_3 is the direct precursor to the formation of ammonium nitrate. We do not know for certain what times of the day the atmosphere is HNO_3 limited nor do we know what the dominant pathway is to HNO_3, however, our hypothesis is that the daytime pathway is dominant. During winter-time cold pool events, clear skies, snow covered ground, and high elevation terrain can lead to

increased actinic flux, increased photolysis rates, and increased OH production. Increased OH production could lead to higher rates of HNO3 production when NO2 and OH react.

UDAQ will test model sensitivity to increased albedo due to snow cover in CMAQ's calculation of photolysis rates. Using typical albedo values for various land use types and snow age UDAQ will select representative albedo values for our simulations. Further sensitivity tests could also incorporate testing of enhanced actinic flux caused reflection from high albedo steep terrain that form valley walls in the Cache Valley and along the Wasatch Front.

Data collected during a UDAQ commissioned study support this hypothesis of increased daytime HNO3 production. The study was conducted by the Brigham Young University Chemistry Department during a 2 month winter period in 2009 (Kuprov, 2010). The study was punctuated with short periods of instrument malfunction that leaves some uncertainty with respect to the conclusions of whether or not HNO_3 formation is greatest at night or during the day.

UDAQ has purchased a URG-9000 instrument and will attempt to verify the 2009 results during the winter of 2010-2011. We believe that analysis of the monitoring data will provide the most robust data set from which to the dominant HNO3 formation pathway. The monitoring data can be used to confirm if CMAQ model chemistry is capturing the appropriate HNO3 formation mechanisms.

1.4.7 $PM_{2.5}$ Concentration Trends

Identifying trends in $PM_{2.5}$ concentrations is difficult due to the nature of the conditions that lead to the formation of stable cold pools. Figure 1.8 shows the 98th percentile value at Hawthorne for the last 9 years. The graph has no trend and is essentially a commentary on a particular winter's weather pattern. Depending on the year, some winters have more periods dominated by semi-permanent ridges. Other winters feature more progressive synoptic flow that limits the duration (and strength) of ridge dominated weather.

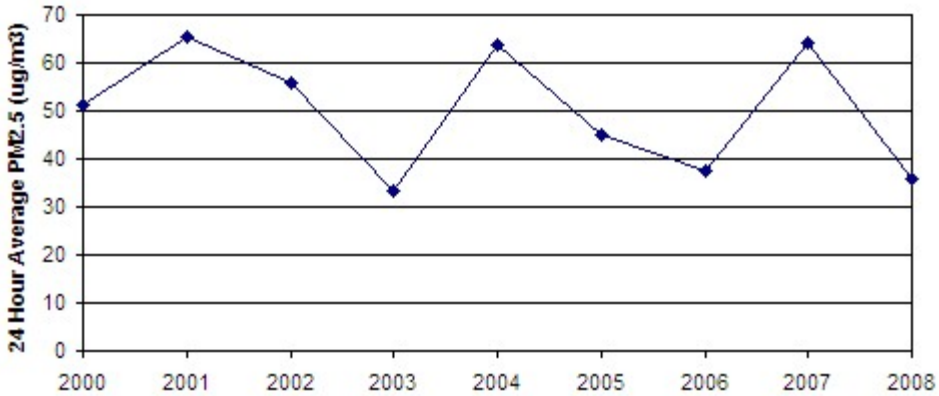

Figure 1.8 Hawthorne 98th percentile $PM_{2.5}$ concentration

1.4.8 $PM_{2.5}$ Modeling Experience

The DAQ modeling team has 8 years of $PM_{2.5}$ grid-based modeling experience. In all modeling cases, we have encountered significant challenges in accurately simulating the cold pools because of the highly variable mesoscale meteorology and chemistry that occurs in Northern Utah's valleys/basins. The lack of synoptic scale forcing produces mesoscale meteorology that is largely terrain driven. Model resolution and data assimilation are not capable of capturing all of the mesoscale features. As a result, our modeling results show that containing the pollutants within the cold pool is a severe weakness of the model.

Our experience consists of the following modeling projects and strategies:

1999: MM5 with UAM-AERO.
2002: Diagnostic Wind Model using all MESOWEST observation stations with UAM-AERO.
2002: Diagnostic Wind Model using selected MESOWEST observation stations with UAM-AERO.
2003: Diagnostic Wind Model using an idealized bi-modal wind field with UAM-AERO.
2007: NCAR RT-FDDA (Real Time Four Dimensional Data Assimilation) MM5 with CMAQ.
2008: NCAR 30 member Ensemble-RT-FDDA (MM5 & WRF) with CMAQ.
2009: WRF with CMAQ.
2010: WRF with CMAQ.

2. Model and Modeling Inputs

2.1 Air Quality, Meteorology, Emissions Model Selection Rationale

Meteorological Model

DAQ has taken 3 approaches to developing meteorological fields for input to CMAQ. The first two approaches involve a partnership that we have formed with the Department of Army Dugway Proving Ground Meteorology Division for meteorological modeling services using NCAR's state of the Science MM5 & WRF modeling systems. In the third approach, DAQ developed in-house WRF customization capabilities.

1) NCAR produced a single MM5 Real Time Four Dimensional Data Assimilation (RT-FDDA) methodology to generate meteorological fields for the January 2007 episode.

2) NCAR ran their Ensemble Real-Time Four Dimensional Data Assimilation (E-RTFDDA) model for our second episode during February 2008. The ensemble system consists of 30 members including 15 MM5 based members and 15 WRF based members. Each ensemble member included unique physics or initialization options. Table 2.1 provides a summary of physics schemes used in the 30 ensemble members.

Physics	WRF	MM5
Cumulus	Kain-Fritsch Betts-Miller-Janic Grell-Devenyi	Kain-Fritsch Grell Betts-Miller-Janic Fritsch-Chappell Kuo
Microphysics	Kessler Lin et al. WSM5 WSM6 Thompson et al. Ferrier	Hsie Dudhia Ice Reisner 1 Reisner 2 Goddard Schwartz
Long-Wave Radiation	RRTM CAM GFDL	RRTM CCM2
Short-Wave Radiation	Dudhia Goddard CAM GFDL	Dudhia CCM2
PBL	YKU Meller-Yamada-Janic RUC GFS	MRF Blackadar Meller-Yamada-Janic Gyano-Seaman
Other	No horizontal diffusion	No horizontal diffusion

Table 2.1 Ensemble member physics combinations

3) DAQ has developed the in-house capability to run WRF. The base case WRF simulation is configured using a 4km horizontal resolution with 40 vertical layers. UDAQ plans to conduct experimental WRF runs using customized physics options, code modifications, landuse parameter changes, initialization variations, FDDA variations, and increased vertical resolution.

These 3 approaches to developing meteorological fields in support of SIP chemistry modeling represent a new level of sophistication. With our three approaches, we attempt to identify numerous model configuration options that the literature has shown to be effective in stable conditions and/or complex terrain in order to develop accurate or conceptually representative meteorological fields for CMAQ.

Air Quality Model

CMAQ was selected because it is the open source atmospheric chemistry model co-sponsored by EPA and NOAA. We are currently using CMAQ version 4.6 and will upgrade to either version 4.7 or the 2010 release for model performance evaluation.

Emissions Model

The emissions processing model used in conjunction with CMAQ is the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE version 2.6). Modeling staff at UDAQ have extensive experience with this model and have been using it on a regular basis since 2001. The

emissions processing model takes the annual, county-wide emissions inventory prepared by UDAQ and reformulates it for use in the air quality model.

2.2 Modeling Domain & Resolution

DAQ selected our high resolution modeling domain to cover all of northern Utah including the portion of southern Idaho extending north of Franklin County and west to the Nevada border (Figure 2.1). This domain was selected to ensure that all of the major emissions sources that have the potential to impact the non-attainment areas were included.

MM5, WRF, and CMAQ are configured using a 4km x 4km horizontal resolution domain. Vertical resolution in MM5 and WRF ranges between 36 and 40 layers as a base case with additional experimentations planned using increased vertical resolution in the lower atmosphere. CMAQ is run using 15 vertical layers with experimentations utilizing all MM5 and WRF layers.

In early simulations of the CMAQ model UDAQ tested a 1.3 km horizontal resolution but found no improvement in chemistry performance. This result confirms other complex terrain horizontal resolution studies conducted by numerous researchers (eg., Roebber 2001, Mass 2001, Hoadley 2004, Zhong 2003, Kain 2008, Zhong, 2005) and a locally conducted study by the University of Utah (Hart, 2005).

Increased horizontal resolution would be more likely to provide increased wind field complexity in the mountains where increased terrain details (i.e. ridges, mountain tops, etc) could effect wind predictions in those elevated areas. The Cache Valley $PM_{2.5}$ problem is confined to the very lowest terrain along the Valley bottom where increased horizontal resolution will not resolve additional terrain details. Furthermore, Randy Martin's $PM_{2.5}$ saturation studies have shown that $PM_{2.5}$ concentrations demonstrate a high level of homogeneity along the Valley bottom (Martin, 2006). The homogeneity suggests that adding detail and complexity to the emissions or meteorological fields should not be a high priority issue.

In 2010, UDAQ will explore running WRF with increased vertical resolution in the 2009 and 2009-2010 episodes. Increased vertical resolution in the lower atmosphere is likely more relevant to simulations of atmospheric stability than would be moving to extremely fine horizontal resolution over flat valley bottoms where the $PM_{2.5}$ is trapped.

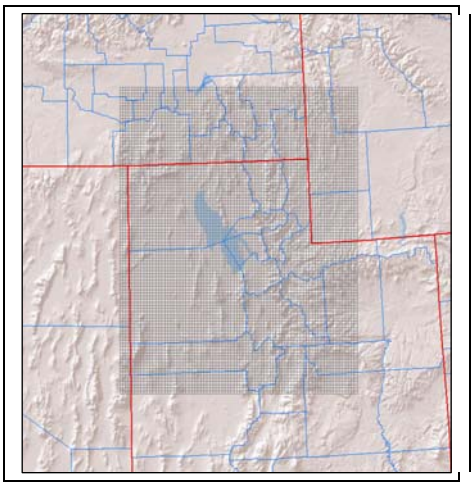

Figure 2.1 Northern Utah and Idaho modeling domain

2.3 Attainment Test Geographic Area

UDAQ proposes to select an area that encompasses all of the non-attainment areas in northern Utah and southern Idaho and use the grid cells within that area to apply the modeled attainment test (Figure 2.2).

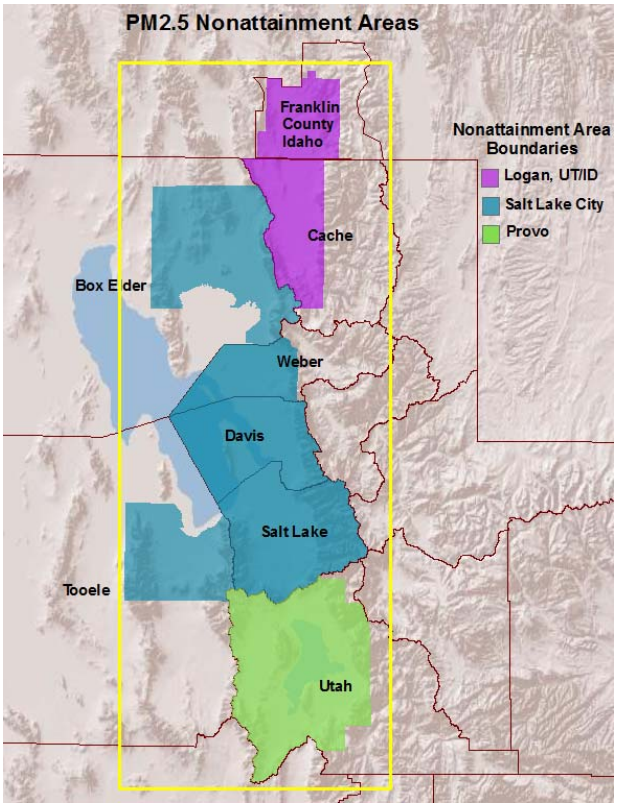

Figure 2.2 Grid cells within the geographic area to be used for the modeled attainment test

2.4 Initial and Boundary Conditions

The ridge dominated synoptic meteorology during $PM_{2.5}$ cold pool episodes features weak transport winds and near calm surface winds. As a result, transport of $PM_{2.5}$ and precursors from the rural regions at the domain periphery is very small. In addition, most of the observed Wasatch Front and Cache Valley $PM_{2.5}$ is formed in-situ (and trapped) via fresh locally derived emission sources and secondary chemistry. In essence, Utah's cold pools represent an isolated system that is controlled only by locally derived emissions, meteorology, and chemistry.

We begin each of our CMAQ model simulations prior to the start of $PM_{2.5}$ build-up. The very small initial concentrations of diurnally produced gaseous concentrations have little consequence to the ultimate build-up of $PM_{2.5}$. DAQ has configured CMAQ to use EPA default profiles for background chemistry concentrations and will consider using a model spin-up approach. UDAQ will supplement the default profiles by using rural values taken from bordering National Park air quality monitoring stations for chemistry initialization.

2.5 Episode Selection

2.5.1 Introduction

The meteorological conditions and chemical processes that lead to elevated PM in Utah occur in very few locations in the United States. The mountain-valley physiography of Northern Utah allows long lasting (up to 2 weeks) stable cold pools to form in valley bottoms. Within the cold pool, extreme atmospheric stability with weak mixing and advection can lead to the build-up of $PM_{2.5}$ concentrations. The uniqueness of our situation creates several significant $PM_{2.5}$ meteorological modeling and atmospheric chemistry modeling challenges that need to be considered during episode selection. The process by which we select $PM_{2.5}$ SIP episodes and design the SIP modeling protocol will be based on experience gained over several years combined with the criteria outlined in the EPA modeling guidance.

The first challenge involves the meteorological modeling of the mesoscale cold pool phenomena that forms along the Wasatch Mountain valleys. Meteorological models have a very difficult time replicating the extreme vertical temperature gradient and vertical and spatial extent of cold pools. In addition, subtle variations in meso to synoptic scale meteorology can have a significant impact on the degree of atmospheric stability and chemistry concentrations. The replication of extreme atmospheric stability and weak near-surface wind field will be the greatest challenge of model development.

Second, gaseous and particulate chemistry modeling is handicapped by an incomplete understanding of the complex chemical processes that operate in cold sub-freezing conditions typical of Utah’s winter cold pools. For example, no data exists for the sub-freezing heterogeneous reaction probability for N_2O_5. A second example comes from recent data published by researchers at Utah State University and University of California at Riverside (Malloy 2009). They found a new significant pathway for the formation of secondary organic aerosols. The pathway may have particular significance in rural areas similar to the Cache

Valley where agricultural animal operations may produce high concentrations of amines. This new pathway is absent from existing chemistry models.

Third, the Federal Reference Method (FRM) for collecting $PM_{2.5}$ measurements is inadequate for our cold temperature, secondary particulate dominated air. Ammonium nitrate (NH_4NO_3) accounts for over 50% of our measured $PM_{2.5}$ mass. NH_4NO_3 can rapidly volatilize off of FRM filters and result in "missing mass" when speciated.

2.5.2 Non-Attainment Area Meteorological Conditions

With the exception of wind blown desert dust events, wild land fires, and holiday related fireworks, elevated $PM_{2.5}$ in Utah occurs when stagnant cold pools develop during the winter season. The synoptic conditions that lead to the formation of cold pools along the Wasatch Front and in the Cache Valley are identical: synoptic scale ridging, subsidence, light winds, snow cover (often), and cool to cold surface temperatures.

While the general synoptic scale meteorological characteristics are identical between these two areas there are important differences related to topography. The Cache Valley is a closed basin with no significant outlets. The Salt Lake Valley has an outlet to the north and is connected to the larger Great Basin. Utah Valley is essentially closed but has numerous complicating terrain features. The northern Wasatch Front is open to the west, north, and south. The degree of basin "openness" may allow for varying amounts of advection of pollutants and corresponding changes in pollutant concentrations and build-up rates. For example, Cache Valley topographical features lead to faster forming, more intense, and more persistent cold pools relative to the Wasatch Front. Because of these differences, the Wasatch Front and Cache Valley are designated as separate attainment areas, however, they will be modeled together within the same modeling domain.

2.5.3 Non-Attainment Area Episode Selection

Episodes for CMAQ modeling will be selected such that observed elevated $PM_{2.5}$ concentrations occur simultaneously along the Wasatch Front and in the Cache Valley. The meteorological similarity between the two basins will allow us to model the same episodes for both non-attainment areas.

2.5.4 Episode Selection Criteria

According to EPA's April 2007 "Guidance on the Use of Models and Other Analyses for Demonstrating Attainment of Air Quality Goals for Ozone, $PM_{2.5}$, and Regional Haze" the selection of SIP episodes for modeling should consider the following 4 criteria:

1. Select episodes that represent a variety of meteorological conditions that lead to elevated $PM_{2.5}$.

2. Select episodes during which observed concentrations are close to the baseline design value.

3. Select episode that have extensive air quality data bases.

4. Select enough episodes such that the model attainment test is based on multiple days at each monitor violating NAAQS.

The following section will describe how Utah will use each of the criteria to choose episodes that will provide the best opportunity for meeting model performance criteria.

1. Select episodes that represent a variety of meteorological conditions that lead to elevated $PM_{2.5}$.

Stagnant cold pools are the only meteorological conditions that produce elevated $PM_{2.5}$ during the winter in Utah's non-attainment areas. The synoptic meteorological conditions that lead to cold pool formation are essentially identical from one episode to another in that stagnant cold pools develop when synoptic scale ridging dominates the region. Variations in temperature, humidity, cloud cover, snow cover, wind speed, stability, emissions, and episode length may produce greater (or lesser) exceedences, but these variations are generally not resolvable by numerical weather models.

Based on our modeling experience, medium length (5 to 10 days) episodes that have a smooth steady build-up of $PM_{2.5}$ concentrations are appropriate for a general analysis of winter inversion episodes. Long episodes (>10 days) tend to have excessive concentration variability produced by subtle meteorological features. An example would be a subtle 700 mb feature that moves through the northern portion of the state. Often, these features pass without notice, but they can provide enough destabilization to briefly stir the surface layer and significantly reduce $PM_{2.5}$ concentrations before rebuilding again. This type of subtle feature will not be captured in the model and will result in poor model $PM_{2.5}$ performance.

Occasionally, a winter season will feature long periods (weeks) when synoptic conditions are dominated by a semi-permanent ridge of high pressure. During these periods, inversion and cold pool conditions persist, but are punctuated by periodic mixing events. A long simulation of this kind of weather pattern can address issues relating to transport and partial mix-outs. Furthermore, a long simulation during which $PM_{2.5}$ builds, and mixes multiple times could prove useful in understanding model strengths and weaknesses.

At this juncture, this modeling protocol will not address 24-hour $PM_{2.5}$ NAAQS exceedences that occasionally occur during the warmer seasons due to high wind events, wild land fires, and holiday related fireworks. Additional discussions with EPA will be required before a decision can be made on how to address this special issue. UDAQ will include a modeling protocol supplement when a decision is made on how to treat these types of exceptional events.

2. Select episodes during which observed concentrations are close to the baseline design value.

Based on our modeling experience it seems appropriate to give more weight to the behavior and characteristics of the episode during periods when the statistical calculation of the 24 hour average $PM_{2.5}$ is over the baseline design value. The model system will perform best when the episode is of medium length and it has a smooth steady build-up. In this case, day one of the episode will feature very low $PM_{2.5}$ concentrations and then build to higher levels on each successive day. The build-up will continue until some meteorological feature either cleans the $PM_{2.5}$ out or produces a partial mixing. The key point is that for all $PM_{2.5}$ episodes, the chemical processes that lead to the secondary formation of $PM_{2.5}$ and the chemical speciation of the $PM_{2.5}$ are similar and lead to very similar speciation profiles as demonstrated in all available PM2.5 speciation data.

3. Select episode that have extensive air quality data bases.

The State of Utah operates or has operated 19 FRM monitors during the years being considered for this SIP. Three real-time TEOM-FDMS (Tapered Element Oscillating Microbalance Filter Dynamic Measurement System) monitors are operated along the Wasatch Front and one is operated in Cache Valley. Three National Speciation Network Monitors are also operated along the Wasatch Front. Hawthorne in Salt Lake City samples 1 day out of every 3 days. Lindon (Utah County) and Bountiful (Davis County) operate 1 day out of every 6 days.

As described in Section 1, Utah faces significant monitoring challenges in our winter-time cold pool phenomena. First, Utah has found that up to 50% of FRM filter mass is lost and or unidentifiable after speciation analysis. The largest portion of lost mass is due to the in-situ and laboratory re-volatilization of particulate ammonium nitrate (NH_4NO_3). NH_4NO_3 represents 50% to 75% of $PM_{2.5}$ mass during $PM_{2.5}$ episodes. As a result, re-volatilization losses have a significant impact on speciation analysis. Second, the teflon filter media used in the $PM_{2.5}$ FRM monitors does not allow for organic and elemental carbon to be analyzed. Carbon species account for 10-20% of our $PM_{2.5}$ mass. These uncertainties with filter media and re-volatilization virtually eliminate the usability of speciated FRM data for our SIP analysis.

The backbone of our speciated model performance analysis and attainment tests will be data from the National Speciation Network. This data has been shown to be very accurate and re-volatilization losses are small. In anticipation of the need for SIP modeling we enacted an intensive operating period during 2 episodes in February 2008 and January 2009. We collected 1 in 2 day sampling at all 3 of Utah's National Speciation Network sites.

As a part of special winter inversion study, DAQ collects speciation data every two days during January and February from the monitoring stations located in Utah and Salt Lake valley. Beginning in winter 2009/2010, DAQ acquired a URG-3000 and a SASS speciation sampler to collect speciation data during the inversion episodes in the Cache valley. The samplers were installed in late winter 2010 and are located at the Logan sampling site. Speciation data was collected at Logan for most of February and March 2010. DAQ will continue to collect speciation data at Logan during the 2010-2011 winter season.

In addition to the February and March speciation data collected at Logan during 2010 speciation data from a mass spectrometry study is available from January – March 2004 (see section 1.4.3).

To supplement our National Speciation Network data we plan is to use the real-time FDMS $PM_{2.5}$ monitors to evaluate hourly model output. This hourly total $PM_{2.5}$ data is critically important to evaluating hour by hour model performance. FDMS data is not speciated, but we have significant confidence in the consistency of the percentage of NH_4NO_3 that is typically measured on the National Speciation Network filters. This consistency will allow us to use the FDMS data to develop hourly pseudo observations of NH_4NO_3 to augment our model performance analysis. Figure 2.3 shows the $PM_{2.5}$ monitoring network.

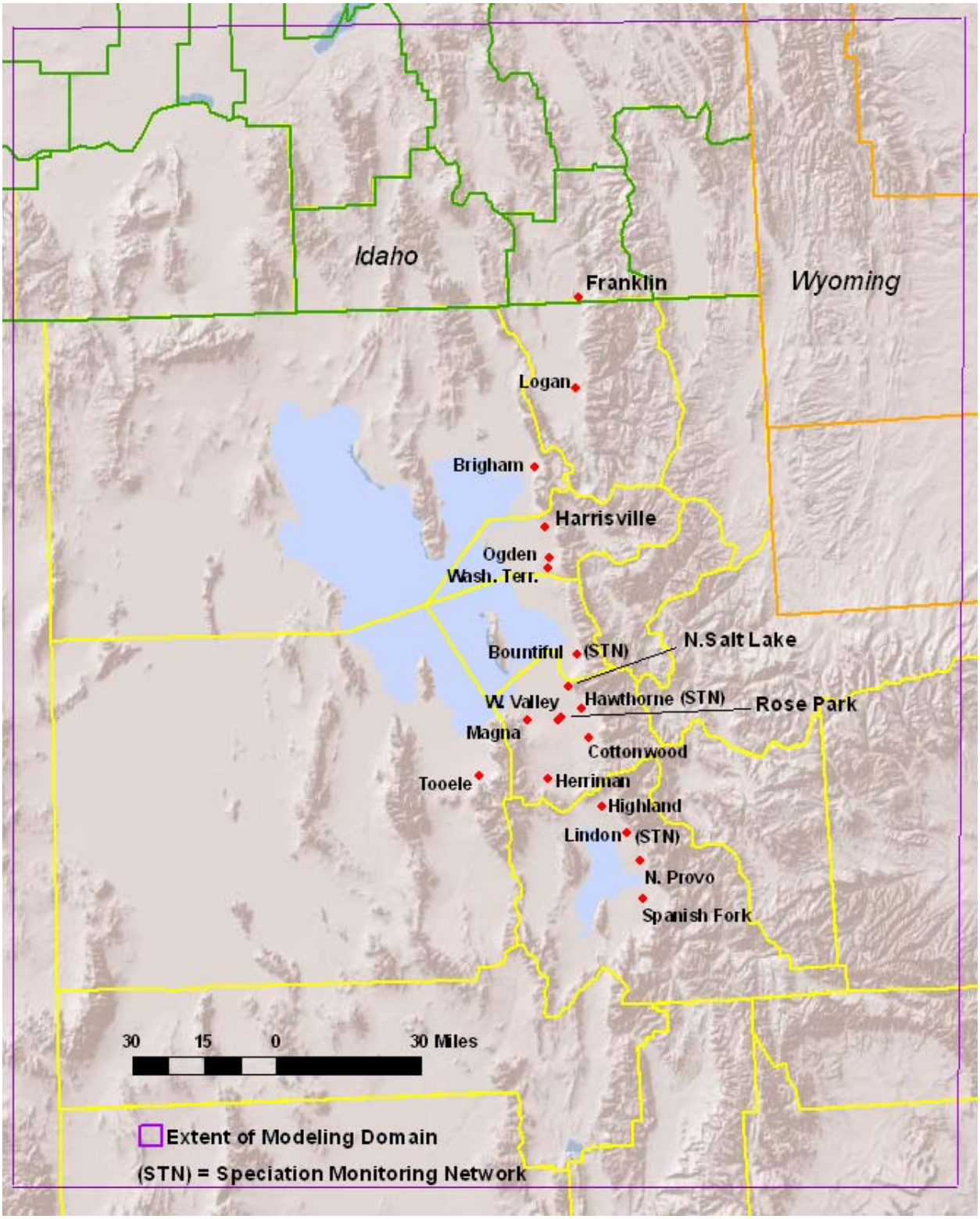

Figure 2.3 UDAQ $PM_{2.5}$ monitoring network

4. Select enough episodes such that the model attainment test is based on multiple days at each monitor violating NAAQS.

For all of our $PM_{2.5}$ episodes, UDAQ's conceptual model is that chemical processes and the chemical speciation are essentially identical. Based on previous modeling experience, we will choose discrete episodes of medium length with a smooth steady build-up of $PM_{2.5}$. These episodes might not necessarily be the episodes of highest $PM_{2.5}$ concentration, but they will provide episodes representative of the processes that lead to NAAQS $PM_{2.5}$ exceedences. Each episode has concentrations close to the design value in accordance with "Criteria 2". Rather than model four or more non-ideal episodes, we have chosen four episodes that will maximize our potential for the most complete characterization of episode dynamics.

2.5.5 Selected Episodes

From the most recent 5-year period of 2005-2009 we developed a long list of candidate $PM_{2.5}$ episodes. Three episodes were selected based on the medium length steady build-up criterion described above. A fourth multi-event episode was selected using the multiple build-up and mix out criteria described above and in more detail in the section titled "Episode 4". In general we want to select episodes with hourly $PM_{2.5}$ concentrations that are reflective of conditions that lead to 24-hour NAAQS exceedences. The episodes that we select may not contain the highest $PM_{2.5}$ concentrations, but will contain concentrations that are reflective of the most frequent observed 24-hour NAAQS exceedence concentrations. For example, Figure 2.4 shows the concentration frequency of 24-hour $PM_{2.5}$ exceedences at our main Salt Lake City monitoring location. Sixty five percent of exceedences at Hawthorne occur when concentrations are less than 45 ug/m^3. Finally, we want to select episodes that have hourly $PM_{2.5}$ data and have speciated data collected by the National Speciation Network. Tables containing available data are included in each selected episode's discussion section.

From a synoptic weather pattern point of view, each of the selected episodes features a similar pattern. The typical pattern includes a deep trough over the eastern United States with a building and eastward moving ridge over the western United States. The episodes typically begin as the ridge begins to build eastward, near surface winds weaken, and rapid stabilization due to warm advection and subsidence dominate. As the ridge centers over Utah and subsidence peaks, the atmosphere becomes extremely stable and a subsidence inversion descends towards the surface. During this time, weak insolation, light winds, and cold temperatures promote the development of a persistent cold air pool. Not until the ridge moves eastward or breaks down from north to south is there enough mixing in the atmosphere to completely erode the persistent cold air pool.

All of the episodes fit this general pattern of building ridge, lowering subsidence inversion, and cold (or cool) pool development, however, each episode has its own variations. For example, the graphics in Appendix 2.1, 2.2, and 2.3 show that the ridge position and strength was different in each episode and each episode's atmospheric stability and cold pool structure was unique. While each episode has its unique characteristics, the commanding similarity between each episode is stability and stagnation that traps locally produce emissions and allows secondary $PM_{2.5}$ formation and concentration build-up.

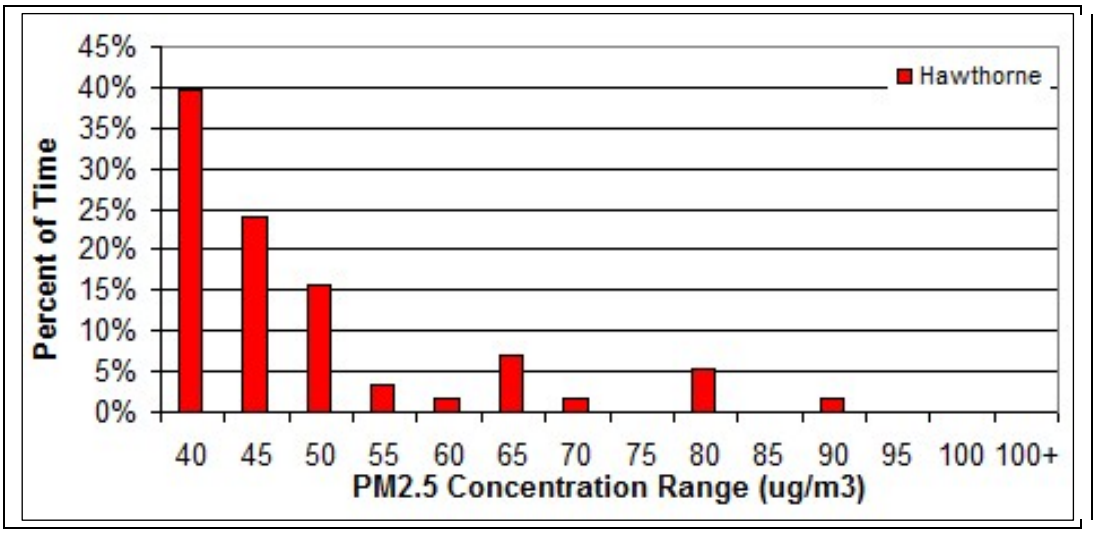

Figure 2.4 Concentration frequency of NAAQS $PM_{2.5}$ exceedences at Hawthorne for 2005-2008. An x-axis value of 40 means $PM_{2.5}$ concentrations between 35 and 40 ug/m3. Approximately 40% of all NAAQS $PM_{2.5}$ exceedences occurred at a concentration between 25 and 40 ug/m3.

The following sections will describe the 3 episodes that we have selected. The descriptions of each episode will rely on $PM_{2.5}$ data collected from our 4 main sites (Logan, Ogden, Hawthorne, and Lindon). Each of these sites features a FDMS monitor and a FRM monitor.

Episode 1: January 11-20, 2007

A cold front passed through Utah during the early portion of the episode and brought very cold temperatures and several inches of fresh snow at the National Weather Service Salt Lake City AWOS observation station (KSLC) began the episode with 3 inches of new snow) to the Wasatch Front. The trough was quickly followed by a ridge that built north into British Columbia and began expanding east into Utah. This ridge did not fully center itself over Utah, but the associated light winds, cold temperatures, fresh snow, and subsidence inversion produced very stagnant conditions along the Wasatch Front. High temperatures in Salt Lake City throughout the episode were in the high teens to mid-20's Fahrenheit. Maximum "mixing depths" during the heart of the episode were in the range of 250m to 300m above ground level (Appendix 2.4).

Figure 2.5 shows hourly $PM_{2.5}$ concentrations from Utah's 4 FDMS $PM_{2.5}$ monitors for January 11-20, 2007. The first 6 to 8 days of this episode are suited for modeling. The episode becomes less suited after January 18 because of the complexities in the meteorological conditions leading to temporary $PM_{2.5}$ reductions. This episode is marginally suited for Cache Valley modeling because hourly concentrations measured at Logan only reach the 40 to 45 ug/m3 range. Table 2.2 shows 24-hour average $PM_{2.5}$ concentrations measured using the FRM. Hawthorne 24-hour averages reached 48.4 ug/m3 on January 17 while Lindon reached 61.7 ug/m3 on January 18. As shown almost 80% of all NAAQS $PM_{2.5}$ historical exceedences measured at Hawthorne occurred at concentrations lower than the January 17 48.4 ug/m3 value. This puts this episode in the top 20% of episodes that occurred between 2005 and 2008 and above the baseline design value.

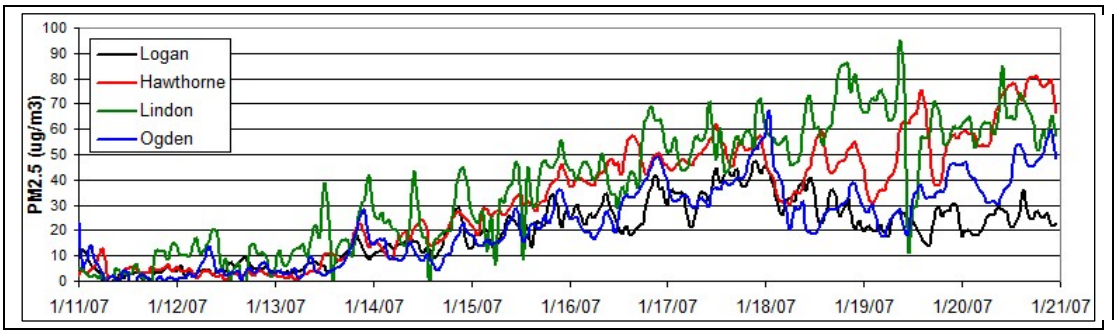

Figure 2. 5 Hourly FDMS $PM_{2.5}$ concentrations for January 11-20, 2007

Table 2.2 24-Hour FRM $PM_{2.5}$ concentrations for January 11-21, 2007. See Appendix 2.7 for a monitoring station look-up table.

Date	BR	L4	BT	CW	N2	MG	HW	WV	HE	T3	NP	LN	HG	SF	O2	WT	NOG	FRK
11-Jan-07		3.0			6.1		5.1					4.7						1.8
12-Jan-07	3.2	6.0	3.5	6.9	8.3		3.5			7.5	9.1	9.5	11.5	7.6	5.9	5.6	3.4	3.3
13-Jan-07		8.1					8.7	12.3				16.0						5.6
14-Jan-07		14.7					17.7											7.2
15-Jan-07	14.0	20.1	27.7	37.4	33.5		31.4	32.0		16.5			29.4	27.9	22.7	21.6	18.4	8.7
16-Jan-07		27.1			47.7		44.8											13.4
17-Jan-07		35.2					48.4											27.3
18-Jan-07	24.9	31.1	29.6	49.8	52.2		42.8	49.4		24.2		61.7	51.5	55.0	31.7	26.2	30.2	19.2
19-Jan-07		22.9			55.6		47.3					66.9						13.4
20-Jan-07		24.6			66.5		65.1					68.9						24.8
21-Jan-07	14.1	18.4	19.8	18.0	20.4	8.1	16.2	25.6		8.8	47.6	42.0	38.6	41.5	27.5		26.2	14.4

Episode 2: February 14-18, 2008

The February 2008 episode features a cold front passage at the start of the episode that brought significant new snow to the Wasatch Front (KSLC began the episode with 6 inches of new snow). A ridge began building eastward from the Pacific Coast and centered itself over Utah on Feb 20th. During this time a subsidence inversion lowered from 700 mb on February 16 down to almost 800 mb by February 19th. Despite the lowering subsidence inversion, the KSLC upper air sounding shows that the afternoon lower atmosphere mixed through a depth of 400 m on February 19th, but it was capped by the very strong subsidence inversion above this level (Appendix 2.5). Temperatures during this episode were mild with high temperatures at KSLC in the upper 30's and lower 40's Fahrenheit.

The 24-hour average $PM_{2.5}$ exceedences observed during the proposed modeling period of February 14-19, 2008 were not exceptionally high. What makes this episode a good candidate for modeling are the high hourly values and smooth concentration build-up. The first 24-hour exceedence occurred on February 16 and was followed by a rapid increase in $PM_{2.5}$ through the first half of February 17 (Figure 2.6). During the second half of February 17, a subtle meteorological feature produced a mid-morning partial mix-out of particulate matter and forced 24-hour averages to fall. After February 18, the atmosphere began to stabilize again and resulted in even higher $PM_{2.5}$ concentrations during February 20, 21, and 22. Modeling the 14th through the 19th of this episode should successfully capture these dynamics. The smooth gradual build-up of hourly $PM_{2.5}$ is ideal for modeling. In Salt Lake and Weber counties, the 24-hour averages

are about 5 ug/m^3 lower than the baseline design value, but are very close to baseline in the Cache Valley and in Utah County (Table 2.3).

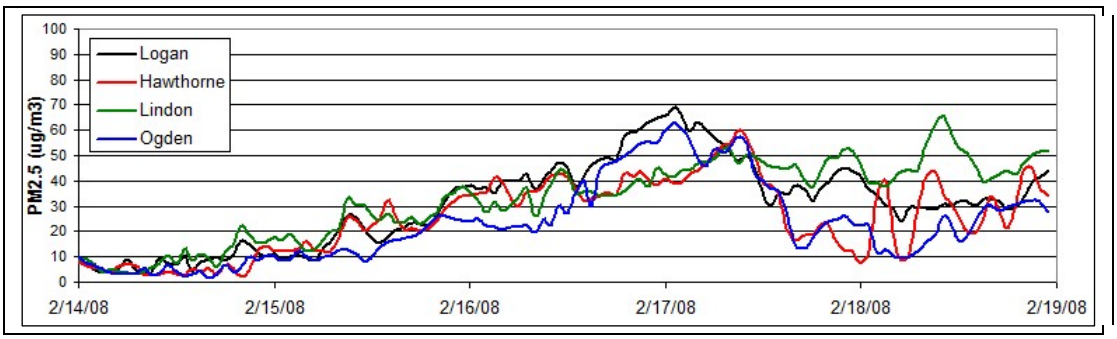

Figure 2. 6 Hourly FDMS $PM_{2.5}$ concentrations for February 14-19, 2008

Table 2.3 24-Hour FRM PM2.5 concentrations for February 14-22, 2008. See Appendix 2.7 for a monitoring station look-up table.

Date	BR	L4	BT	CW	N2	MG	HW	WV	HE	T3	NP	LN	HG	SF	O2	WT	NOG
14-Feb-08		5.6		4.6			5.0				9.4	9.0			3.6		
15-Feb-08	10.7	18.5	19.7	17.9		12.2	19.0		13.6	8.9	23.0	24.2	17.2	24.2	13.2	11.3	12.9
16-Feb-08		42.8		36.5			35.3				33.0	35.5			32.3		
17-Feb-08		42.7		36.8			31.1				45.9	45.6			36.2		
18-Feb-08	22.7	29.7	21.2	23.2		17.6	26.4	31.5	13.5	8.8	39.5	46.3	26.2	27.6	19.9	17.7	23.0
19-Feb-08		40.5		36.3			37.4				37.0	44.7			29.2		
20-Feb-08		49.2		47.2			44.2				36.2	42.2			35.6		
21-Feb-08	43.4	69.2	49.4	43.6		43.9	42.3	45.5	42.3	36	46.1	44.7	38.4	43.3	46.4		44.7
22-Feb-08		71.5		18.2			15.3				19.6	18.3			29.6		

Episode 3: January 13-23, 2009

The third episode also featured a cold front passage with light snow (KSLC began the episode with 2 inches of new snow) and a strong ridge that built eastward from the Pacific coast. Salt Lake City temperatures during this episode began in the lower 40's but cooled to the mid-30's as the cold pool strengthened. The ridge centered over Utah on January 20 and the subsidence inversion lowered to nearly 850 mb. This very strong subsidence allowed a strong cold pool to form and prevented virtually all vertical mixing. Maximum afternoon mixing depths recorded by the KSL sounding were between 0 and 200 m above ground level (Appendix 2.6).

Extremely high concentrations of $PM_{2.5}$ formed during this cold pool episode (Figure 2.7 and Table 2.4). Hourly $PM_{2.5}$ concentrations at Hawthorne increased from near zero on January 14 to 99 ug/m3 six days later on January 19 (Figure 2.5). $PM_{2.5}$ concentrations built steadily through the episode, however, extreme diurnal concentration swings occurred at Hawthorne. We believe that these observed concentration swings are the result of instrument malfunction. At temperatures below freezing and higher relative humidity the dicot heads on the FDMS machines freeze and plug the inlet resulting in an apparent dramatic decrease in $PM_{2.5}$ concentrations.

Prior to this episode DAQ had contracted with Brigham Young University (BYU) atmospheric chemists Dr. Jaron Hansen and Dr. Delbert Etaugh to execute a measurement field campaign at the Salt Lake City Hawthorne site in order to capture a significant $PM_{2.5}$ episode during the

winter of 2009. BYU used a URG 9000 instrument to measure nitrite, nitrate, and sulphate along with all of the regularly collected species at the Hawthorne site. In addition, DAQ ran the National Speciation Network $PM_{2.5}$ monitor on an every other day schedule to capture as much speciated $PM_{2.5}$ data as possible.

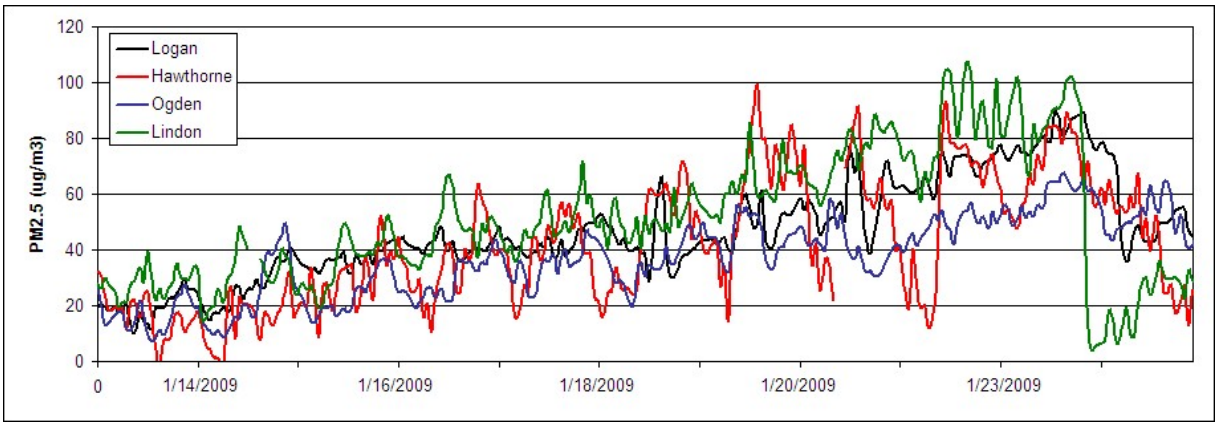

Figure 2. 7 Hourly FDMS $PM_{2.5}$ concentrations for January 14-24, 2009.

Table 2.4 24-Hour FRM PM2.5 concentrations for January 18-26, 2009. See Appendix 2.7 for a monitoring station look-up table.

Date	BR	L4	BT	CW	N2	MG	HW	WV	HE	T3	NP	LN	HG	SF	O2	WT	NOG
8-Jan-09		9.7		12.2			12.3				30.8	35.7			8.1		
9-Jan-09		4.6		6.3			6.2				5.3	5.1			5.6		
10-Jan-09	20.5	16	16	15.4		9.9	16.2			4.7	20.2	24.5	17.8	20.5	19.7		18.5
11-Jan-09		21.9		18.5			18.3				23.8	30.4			18.8		
12-Jan-09		19.2		22.2			22.3					32.5			25.2		
13-Jan-09	12.5	14.9		16.6		7.8	15.7			13.0		26.4	14.9	33.0	12.6		11.7
14-Jan-09		21.7		16.5			16.5				27.0	31.6			20.6		
15-Jan-09		30.7		29.7			31.7				31.6	36.1			20.8		
16-Jan-09	27.2	35.0	25.3	33.7		31.3	37.4			20.7	38.0	44.9	31.8	39.9	25.2		27.0
17-Jan-09		36.1		46.8			47.3				45.7	49.3			31.9		
18-Jan-09		35.1		51.2			55.6				52.2	50.4			33.5		
19-Jan-09	38.6	41.7	55.9	63.9		52.1	69.2			33.3	56.7	63.9	58.1	59.2	41.7		41.1
20-Jan-09		47.9		65.5			69.8				72.8	75.6			37.4		
21-Jan-09		58.5	53.3	74.3			66.9				69.3	80.4			45.6		
22-Jan-09	47.9	68.9		72.8		69.0	72.1			67.0	78.2	73.1	52.8	77.3	56.4		51.2
23-Jan-09		44.0	43.3	48.2			51.3				15.4	17.4			48.7		
24-Jan-09		14.3		12.8			13.9				13.7	13.1			17.7		
25-Jan-09	3.6	5.7	5.6	4.6		2.2	5.2			2.1	3	3.2	1.5		3.3		3.1
26-Jan-09		5.4		5.1			5.4				5.5	7.3			5.1		

Episode 4: December 8, 2009 – January 22, 2010

The fourth episode that was selected is more similar to a "season" than a single $PM_{2.5}$ episode. During the winter of 2009 and 2010 Utah was dominated by a semi-permanent ridge of high pressure that prevented strong storms from crossing Utah. This 45 day period was characterized by 5 to 6 individual $PM_{2.5}$ episodes each followed by a partial PM2.5 mix out when a weak weather system passed through the ridge. The long length of the episode and repetitive PM2.5

build-up and mix-out cycles makes it ideal for evaluating model strengths and weaknesses and $PM_{2.5}$ control strategies.

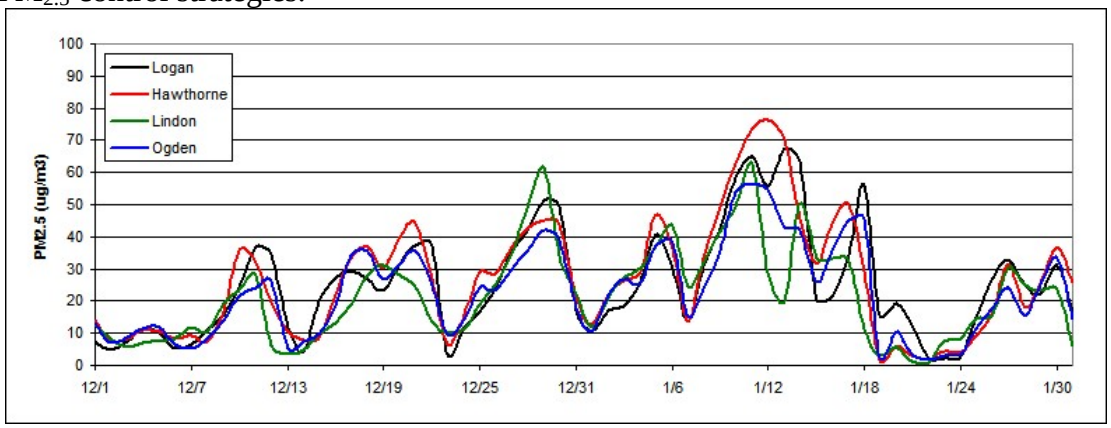

Figure 2.8 24 hour average FRM $PM_{2.5}$ concentrations for December-January, 2009-10.

Table 2.5 24-Hour FRM PM2.5 concentrations for December-January, 2009-10. See Appendix 2.7 for a monitoring station look-up table.

Date	BR	L4	BT	CW	MG	HW	T3	NP	LN	HG	SF	O2	NOG	FRK
12/8/2009		10.8		10.4		7.4	11.1	8.1	10.3			8.3		
12/9/2009	10.8	16.0	13.5	20.1	12.4	16.6	6.7	14.2	19.2	15.0	14.1	13.8	10.6	9.3
12/10/2009		24.2		24.5		35.5	9.9	20.8	23.3			21.3		
12/11/2009		37.0		35.5		32.1	20.4	23.9	28.0			24.2		
12/12/2009	27.0	34.7	28.2	21.2	20.2	19.9	18.4	9.7	6.0	6.7	4.9	26.5	18.2	26.5
12/13/2009		11.8		8.1		10.6	8.2	3.0	3.7			5.2		
12/14/2009		4.0		8.4		7.7	7.9	5.3	5.0			7.5		
12/15/2009	9.6	19.7	9.7	10.4	6.2	8.3	5.4	8.2	9.5	4.9	2.7	9.8	8.7	12.7
12/16/2009		27.1		21.9		22.1	17.8	11.0	13.0			18.4		
12/17/2009		29.5		35.7		33.3	17.7	15.6	18.7			34.2		
12/18/2009	30.4	26.6	38.0	42.8	30.6	37.0	19.2	22.8	28.0	25.1	17.7	35.4	32.6	33.1
12/19/2009		23.1		41.0		30.1	21.8	26.2	31.1			26.8		
12/20/2009		31.5		40.3		39.8	20.5	29.8	28.1			31.7		
12/21/2009	30.8	37.2	14.2	49.5	27.6	44.1	20	19.8	24.7	14.6	14.9	35.5	29.2	42.6
12/22/2009		37.4		29.8		27.2	20.4	10.5	13.8			25.1		
12/23/2009		3.3		6.8		6.6	9.8	8.5	10.2			9.5		
12/24/2009	10.8	12.0	35.5	21.0	13.0	15.6	8.4	8.0	11.3	11.7	7.0	14.4	12.6	7.5
12/25/2009		16.8		32.3		28.8	17.2	13.8	19.0			23.9		
12/26/2009		23.7		33.0		28.4	19.3	21.5	24.9			23.4		
12/27/2009	25.6	35.5	44.1	46.3	34.9	36.9	26.1	29.2	34.5	34.5	27.2	30.0	30.2	
12/28/2009		41.7		51.8		42.6	40.5	42.3	48.5			35.6		
12/29/2009		51.4		53.2		45.4	41.1	57.3	61.3			42.1		
12/30/2009	35.5	49.4			32.0	43.8	23.2	34.8	34.1	25.4	43.3	39.2	37.6	40.3
12/31/2009		17.1		23.5		21.3	4.5	21.5	22.2			17.9		
1/1/2010		10.7		15.8		12.9	12.9	9.4	11.9			10.6		
1/2/2010	18.8	17.3	23.8	22.3	16.4	21.9	6.9	18.8	21.1	11.4	19.6	21.8	20.4	11.7
1/3/2010		18.3		26.3		26.5	14.6	18.0	27.1			26.6		
1/4/2010		25.9		32.2		29.1	19.9	23.3	30.1			25.3		
1/5/2010	50.0	40.6	43.4	45.9	34.1	46.8	25.9	30.6	36.8	30.0	28.0	37.1	39.3	
1/6/2010		30.2		38.3		36.2	30	38.1	43.6			38.3		
1/7/2010		13.6		14.1		13.7	11.4	19.7	24.4			15.4		
1/8/2010	21.8	30.9	31.1	34.7	28.0	33.1	22.2	25.7	31.8	25.7	27.6	23.7	23.1	23
1/9/2010		42.5		50.3		49.3	40.4	39.9	41.7			35.5		
1/10/2010		58.3		62.5		62.7	45.7	49.0	49.2			54.1		
1/11/2010	48.8	64.7	56.9	73.6	63.2	73.5	42.4	62.6	62.8	57.7	59.8	56.3	55.3	44.9
1/12/2010		55.6		70.5		76.4	45.8	31.9	28.8			55.0		
1/13/2010		67.5		60.8		70.8	41.8	16.1	19.7			42.8		
1/14/2010	51.9	63.7	36.8	43.7	28.0	45.5	13.3	53.2	50.6	39.1	51.6	42.0	43.4	70
1/15/2010		20.6		26.4		31.6	15.1	28.7	33.5			26.1		
1/16/2010		21.4		36.9		43.7	24.4	30.8	33.1			35.7		
1/17/2010	46.1	34.1	45.6	47.3	35.9	50.1	32.3	33.0	32.4	21.6	29.8	45.4	39.3	34.2
1/18/2010		56.3		29.2		29.6	28.2	10.8	11.4			45.6		
1/19/2010		15.8		2.0		1.9	6.7	2.9	3.2			2.8		
1/20/2010	8.7	19.1	6.8	4.9	3.5	6.2	2.9	4.9	5.9	4.4	3.1	10.4	10.3	13
1/21/2010		12.8		2.6		3.2	6.8	1.4	1.3			3.6		
1/22/2010		2.0		1.2		1.8	7.2	0.9	0.8			1.9		

2.5.6 Summary

Utah faces several significant $PM_{2.5}$ modeling challenges. The biggest challenge will be to develop meteorological fields that are able to resolve the extreme stagnation that leads to the buildup of PM2.5 during winter cold pool episodes. These challenges are unique to Utah and

may require unique adaptive approaches to modeling. The episode selection process utilizes EPA episode selection criteria in conjunction with DAQ modeling experience to select episodes that provide the best opportunity for meeting model performance criteria and more importantly, appropriately characterize Utah's $PM_{2.5}$ problem.

2.6 Modeling Setup

Most of these technical details will be finalized when we have our final and official base case runs of WRF and CMAQ. The section will include all of the various physics options, initialization detail, nudging details, model version, etc of WRF, MCIP, & CMAQ.

2.7 Emissions Inputs

2.7.1 Introduction

The emissions processing model used in conjunction with CMAQ is the Sparse Matrix Operator Kernel Emissions Modeling System (SMOKE version 2.5). Modeling staff at UDAQ have extensive experience with this model and have been using it on a regular basis since 2001. The emissions processing model takes the annual, county-wide emissions inventory prepared by UDAQ and reformulates it for use in the air quality model. There are three aspects to this reformulation of the inventory which, in the end, produces a refined version of the inventory.

1) Temporal processing: Convert emissions from annual to daily and hourly values.
2) Spatial processing: Convert emissions from a county-wide average to emissions in a 4 square kilometer grid cell.
3) Speciation: Break $PM_{2.5}$ and VOC emissions into their component subspecies using the latest, Carbon Bond 5, speciation profiles.

The process of breaking down the emissions inventory into time and space-resolved components for the air quality model is done with sets of activity profiles and associated cross reference files. These are created for point or large industrial source emissions, area sources which are small but spread out over large areas such dry cleaning establishments, and mobile sources such as automobile and truck traffic. The existing inventories of primary $PM_{2.5}$ and $PM_{2.5}$ precursors are modified to reflect winter conditions for each episode-year. Because of the interaction with ammonia in the formation of ammonium nitrate, special attention is paid to ammonia sources in the modeling domain and all aspects of the inventory are reviewed thoroughly for accuracy and completeness. The 2008 annual inventory will be used to create the future year projection inventories.

Emission inventories are calculated on an average time scale that is far more generalized than what is required by the air quality model. Most activities such as fuel combustion or evaporative processes are estimated for an annual average. The mobile emissions model is used to create an hourly profile of emissions. However, estimated vehicle miles traveled (VMT) is, itself, calculated as an annual average. Consequently, a significant amount of time is spent in the creation and quality assurance of temporal profiles used to disaggregate the annual data into monthly, daily, and hourly slices needed for model-ready emissions files.

The emissions from large industrial sources are placed at the location of the source itself. For area and mobile source emissions, spatial surrogates are created. For example, the emissions from wood stoves for home heating are placed in the model using population density as the surrogate. Using this approach no wood stove emissions for home heating will be put into the model in areas of the county that are unpopulated. Emissions from automobiles are distributed using traffic estimates from the traffic demand model, where available and from road locations and population density in areas not covered by traffic demand modeling.

Splitting the $PM_{2.5}$ and VOC emissions into subspecies is done to allow the air quality model to process the chemical reactions in the atmosphere. Since the reaction of these subspecies in the air accounts for a significant part of the total $PM_{2.5}$ concentrations along the Wasatch Front and in the Cache Valley it is important to account for them. A set of chemical profiles and cross reference files is created for the sources of these emissions and used for this processing. Once the emissions are speciated, the individual species serve as input to the air quality model.

Once cross reference tables are created to define the relationships between the annual emissions inventory and the temporal, spatial, and chemical aspects of the data the SMOKE emissions model is run. Figure 2.9 shows the daily emissions inventory of five important pollutants for the Wasatch Front as well as Cache, Box Elder, and Tooele counties for 2008.

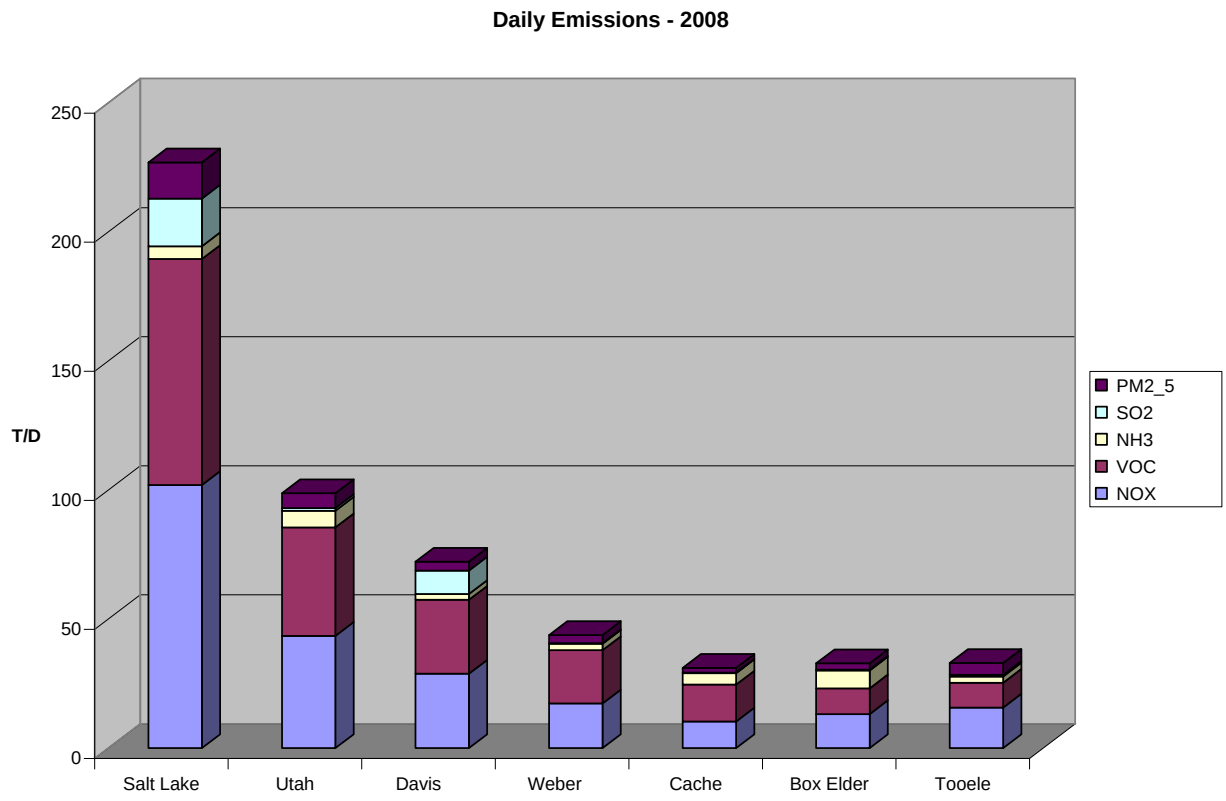

Figure 2.9 Day-specific emissions inventory for February, 2008

2.7.2 Idaho and Wyoming Inventory

Since the Cache Valley extends into Idaho, Utah is providing the air quality modeling to the state of Idaho in support of their SIP for the non-attainment area that extends into Franklin County, Idaho. To provide this analysis UDAQ extended the domain northward a significant distance north of Franklin County to avoid model edge-effects in the air quality model results.

Idaho Department of Environmental Quality (IDEQ) staff will provide the emission inventory that is consistent with the modeling input created by UDAQ.

Regional transport of emissions during winter time inversions is insignificant. Since Wyoming is far-removed from the problem valleys in the Utah and Idaho, and because the state of Wyoming has not yet created a SIP-based emissions inventory, data from the 2005 NEI will be used as the base inventory. UDAQ, with the assistance of Region 8, will make every effort to obtain an updated emissions inventory for Southwest Wyoming including the latest oil and gas inventory. This will be distributed throughout the portions of the counties in the domain using population surrogates.

Parts of three counties in southwest Wyoming are also in the modeling domain simply because the domain is rectangular and extends to eastward and northward limits that encompass part of the state. Given the limited regional transport of emissions during winter time inversions it is unlikely that the emissions from Wyoming will have significant impact on the non-attainment areas of the Cache valley.

Wyoming emissions were downloaded from the WRAP EDMS data base. The version of the inventory used is “version 11, 2005 preliminary”. Emission inputs and SMOKE output reports were sent to Wyoming DEQ on January 13, 2010 for review. A response from the state of Wyoming on February 16, 2010 indicated that the emission inventory group there did not have any further information that they wished to add to the inventory. Nor did they feel that any changes to the data were necessary. Figure 2.10 shows the portions of Idaho and Wyoming that are in the air quality modeling domain.

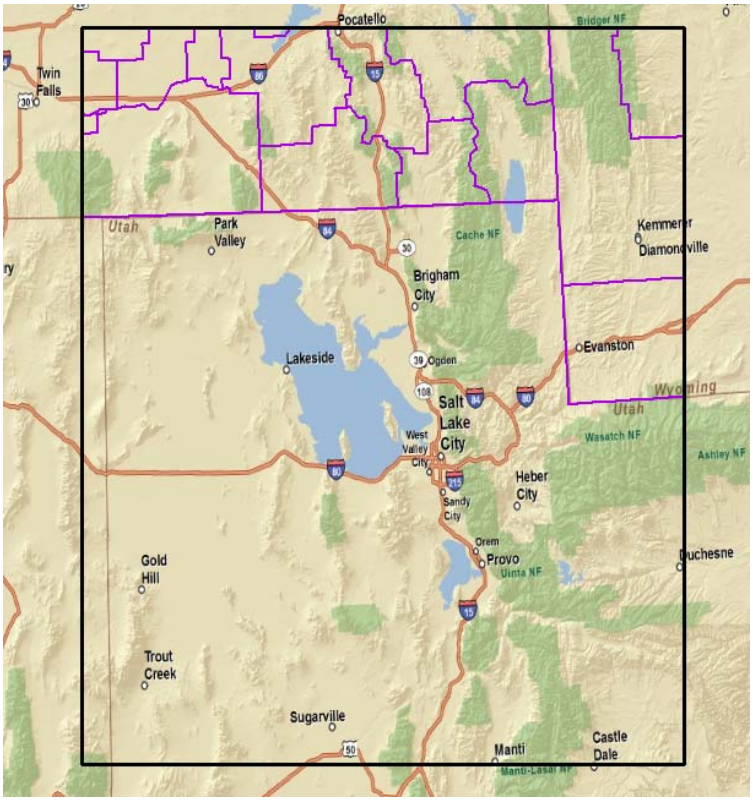

Figure 2.10 Areas of Idaho and Wyoming in the UDAQ modeling domain

2.7.3 Spatial Surrogates used for Distributing Emissions

The function of the emissions model in developing the air quality inputs is to allocate a generalized, county-wide annual emissions inventory into a much more detailed set of emissions. Before SMOKE can be run to create input for the air quality model several types of data sets must be created using a geographic information system (GIS). This pre-processing allows the emissions to be distributed spatially to individual grid cells throughout the modeling domain. Day-specific information, which is available for the mobile and non-road portions of the inventory can also be incorporated into the model.

This section describes the process of creating those inputs for the CMAQ air quality model. One of the most time consuming tasks in creating a model-ready emissions inventory is the creation of spatial surrogates. A spatial surrogates cross reference file is used by SMOKE to disaggregate the county-level inventory to individual grid cells in the modeling domain.

GIS processing is used extensively to produce the cross referenced index file that has the percent of each surrogate, in the individual grid cells, within each county. One of the most important surrogates, population, is created from 2000 census data that is tracked by a geographic unit known as a census block-group. The extraction and recombining of the various GIS layers into the final data set is done mostly through programming code during and after the Arc GIS processing.

Extensive QA/QC is done throughout all phases of the surrogate creation to insure that correct percentages of each category are maintained in the individual grid cells.

As mentioned in the section above, the surrogate created for population density is arguably the most important of the spatial surrogates. The majority of the area source emissions as distributed by population density. In the urbanized counties mobile emissions from local roads are distributed by population density. In all of the outlying/rural counties, mobile emissions from arterial and local roads are distributed with the population surrogate.

The creation of the population density surrogate is a 5 step process:

1. Convert the census data from an absolute number in varying geographic boundaries into a population density number (population per square-meter).
2. Keep track of the population by each individual county so each county-specific emissions inventory can be properly distributed.
3. Convert population density from population/sq. meter to population/16 sq. kilometers (the area of each grid cell).
4. Convert these values into percentages and quality-check the results so that the percentages in the grid cells of each county sum to 1.
5. Employ a special procedure for counties that are only partially covered by the modeling domain (see section below on the creation of population surrogates for Wyoming for a detailed description of this method).

As a further refinement to this process, high-resolution aerial photography is used to eliminate small percentages of population in areas that are clearly devoid of any type of settlement. Figures 2.11 and 2.12 show the results of applying this type of filter to the surrogate creation process.

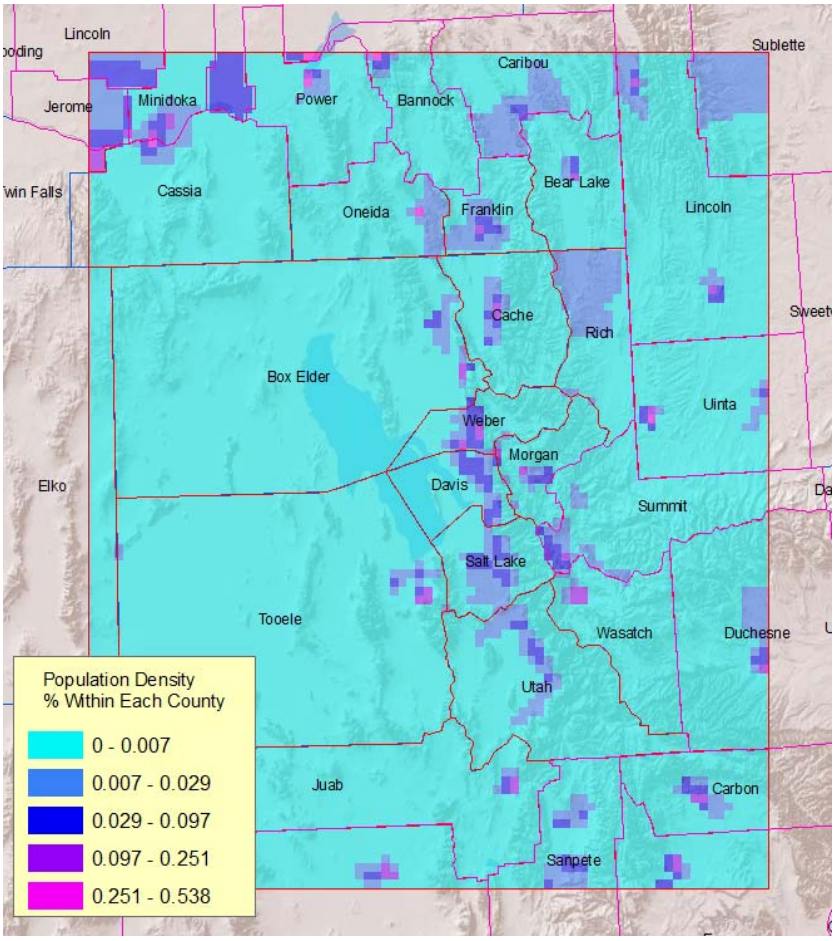

Figure 2.11 Population density by-county

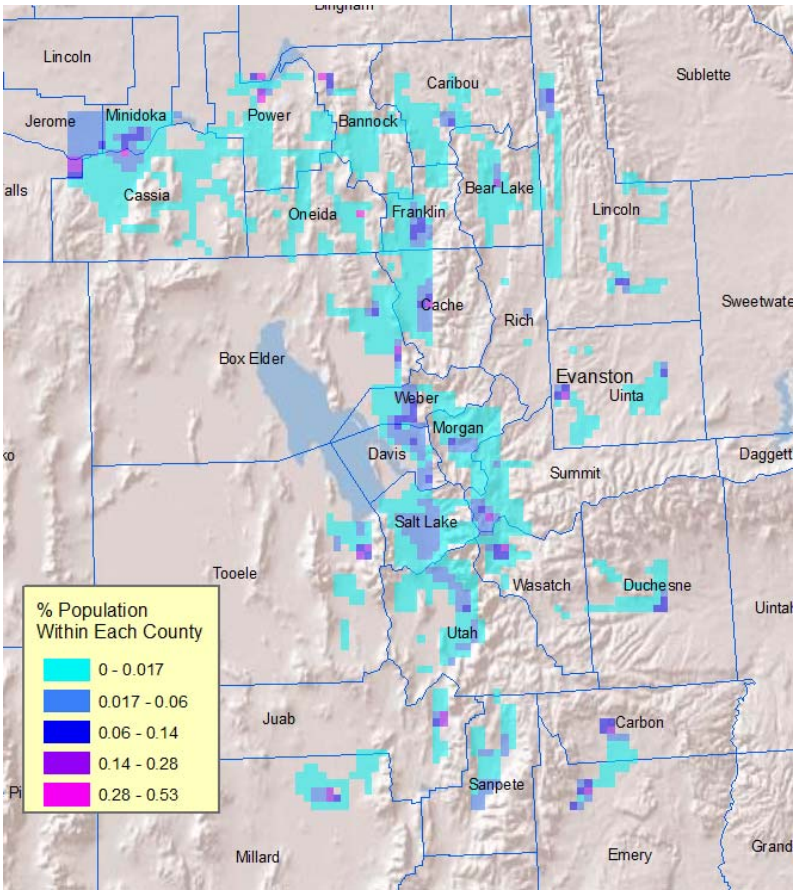

Figure 2.12 Population surrogate distribution after eliminating cells without population

2.7.4 Method to Create Partial-County Emission Inventories

In each state there are a number of counties that are only partially covered by the modeling domain. The example described below shows how a full county-wide inventory is apportioned to areas of the domain that do not cover the full county area. This is done using a five step process.

1) Use the latest Traffic Analysis Zone geography and population data (2006) from the Wasatch Front Regional Council for the four Wasatch Front counties.
2) Use the census "blockgroup" GIS layer to obtain the year 2000 population for all other counties.
3) Use a series of "gridding" functions in GIS to get a population density for each grid cell of the modeling domain in each county.
4) Sum up the population in all of the grid cells in a particular county and divide that number by the total population in the county.
5) Use the result of step number 3 to factor the county-wide emissions inventory.

For example, if 75% of a county's population is within the modeling domain, the spatial surrogate for each grid cell in the county will account for a matching reduction of the full county inventory during the SMOKE model processing.

The emissions inventory for Wyoming will be dealt with as a special case regarding partial-county inventories. The full county-wide emissions inventories for each of the three counties within the domain will be used even though each of the Wyoming counties is only partially within the modeling domain. This is a conservative approach that ensures the inclusion of all emissions from the Wyoming inventory used by UDAQ in the modeling.

2.7.5 Temporal Processing

Updating the temporal, spatial, and speciation profiles has been an ongoing process at UDAQ. The kinds of changes that were made to these profiles and the research done for them are not time dependent and so the profiles continue to be current and valid for all inventories. Spatial profiles, in particular, continue to be updated when necessary to reflect changes in population and economic activity distributions over time. The technical support documentation for the SIP modeling will contain a section that deals specifically with the emissions inventory processing. Any changes to the temporal, spatial, or speciation profiles for specific SCC codes will described in an appendix attached to that document.

The goal of temporal processing is to provide more detail about the emissions inventory during the actual episode being modeled. For example, beginning with annual average data, one first decides how the activity is distributed over the year. A larger proportion of emissions from home heating fuels will occur during the winter months as opposed to summer. Next would be the distribution throughout the month. For automobile emissions one might assume that there is a difference between the amount of daily driving done on the weekends and that done during the work week. Since the modeled episodes run longer than one week the amount of mobile source emissions on the weekend and non-weekend days is adjusted accordingly. The final level of temporal refinement seeks to distribute the emissions throughout the day. If a particular industrial process operates seven days a week but only at night, those emissions will be put into the model only during those hours of operation.

The following figures show examples of temporal profiles for specific SCC codes from the mobile, area and point source categories. These are chosen to show an example from each of the three levels of processing. Figure 2.16 shows the seasonal profile for prescribed burning which shows no burning during winter months. Figure 2.17 shows the weekly profile of one particular process at a large industrial source, and Figure 2.18 shows the hourly emissions profile for six different sources.

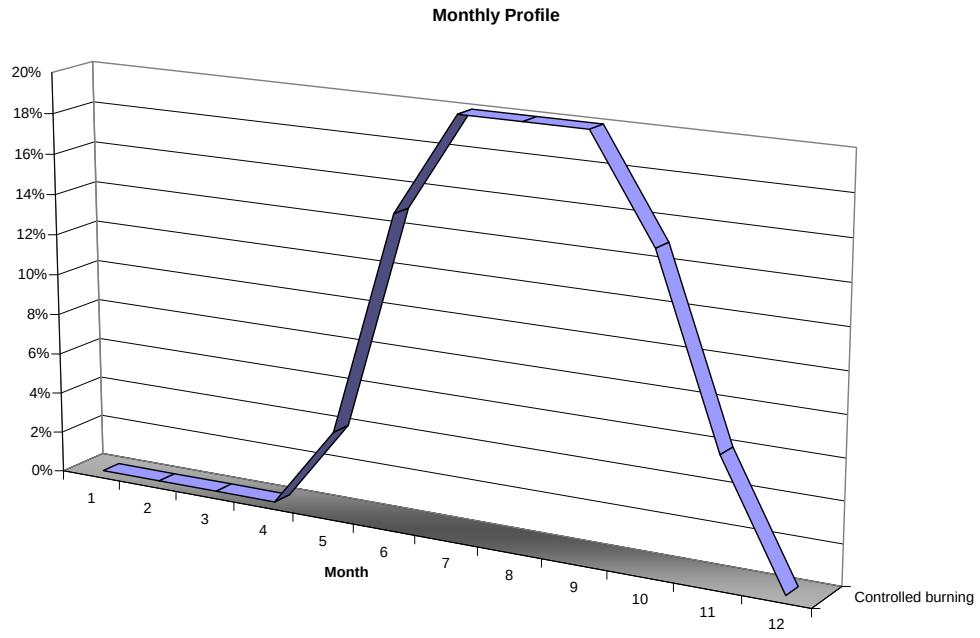

Figure 2.16 Monthly profile of controlled burning emissions

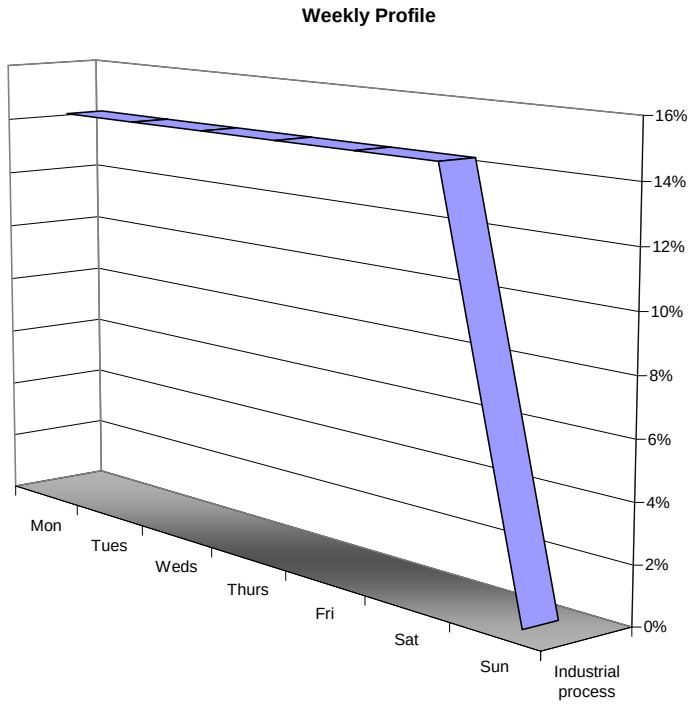

Figure 2.17 Daily profile of large industrial source emissions

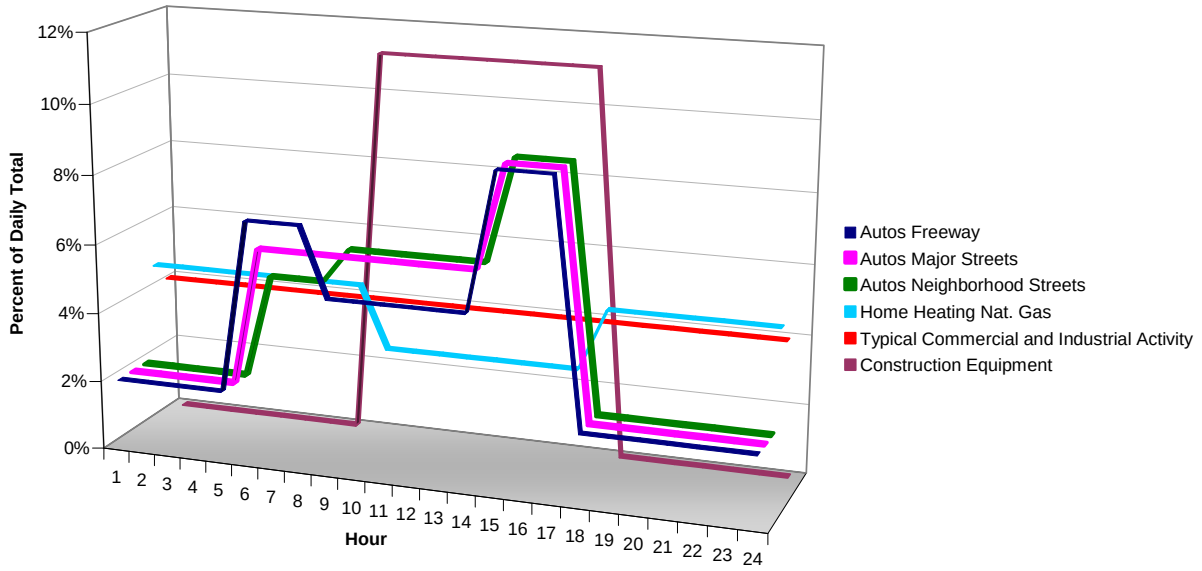

Figure 2.18 Hourly emissions profile for area, mobile, non-road, and industrial sources

Development of area source temporal profiles has been an ongoing process at UDAQ. The SMOKE model has a set of cross referenced index files which the program uses to link emissions from specific SCC codes to variations in seasonal, daily, and hourly inputs to the air quality model. These profiles are represented graphically in figures 2.16 – 2.18, above. UDAQ has changed and edited many of the default profiles to reflect common understanding of activities that take place on a seasonal basis. Figure 2.16 shows a change which reflects the seasonal distribution of open burning activities. Other applications include the concentration of emission estimates from snow blowers into the three month winter season, the exclusion of yard maintenance emissions during the winter, and a significant reduction in emissions from cut-back asphalt application during winter. Many more examples could be listed. In addition, for activities where a common understanding exists about whether they take place seven days a week or just during the work week, and specificity about the activity during the day, these are also reflected by changes in the profiles.

Temporal profiles for on-road mobile sources are developed using the default profiles included with the MOVES model. UDOT is currently developing county-specific temporal profiles for road and vehicle classes in Utah. If these profiles differ significantly from those used by MOVES, those changes will be reflected in SMOKE temporal profiles and the inventory will be reprocessed to account for those changes.

The first iteration of changes to temporal profiles for individual point sources emitting 50 tons or more of PM_{10}, SO_2, NO_x, or VOC were undertaken during the modeling phase of the PM_{10} re-

designation SIP. The modeling for this project was begun in early 2003. For each specific episode period questionnaires are sent to large sources for information regarding special circumstances that may have affected operating conditions. If adjustments to the episode-specific inventory are needed based on the questionnaire results, these adjustments are made before processing the inventory with SMOKE. Detailed lists of the temporal, spatial, and speciated cross reference files will be provided as appendices in the technical support documentation.

2.7.6 Inputs for Base and Future Year Episodes

The annual inventory for area and point sources is used with SMOKE temporal and spatial profiles for each individual episode. Point source data is also adjusted, where necessary, based on a detailed questionnaire sent to the largest sources asking for information about any special circumstances that may have applied during each episode. These emissions will be based on the 2008 triennial inventory. The detailed methodology for the development of the entire emissions inventory is found in the Inventory Preparation Plan document (IPP). Point sources are described in Section V and area sources in Section VI of that document.

On-road mobile source emissions will be created with the MOVES model. MOVES will calculate emissions for a 24-hr (daily) averaging period, and the temporal profiles of SMOKE will then subdivide these emissions into hourly values. On-road mobile source emissions will be geographically positioned within the rural areas of the modeling domain by using population as a surrogate. In the urbanized areas, emissions will be positioned using an overlay of the transportation network. Details of the mobile emissions inventory development are found in Section VII of the IPP.

Another source of emissions to be accounted for in the projection year modeling is the sum of banked emissions that can potentially be used to offset future emissions increases in non-attainment areas. The banked emissions will be included in the modeling analysis as outlined below:

1) Banked emissions will be modeled as a constant amount throughout each of the projection years.
2) Banked emissions will be located in the modeling domain in the same county in which they are registered.
3) Within each particular county, banked emissions will be located in what is considered to be a core industrial area. This area or areas will be placed in the modeling domain as a collection of grid cells and labeled “pseudo sites”. Banked emissions will then be distributed evenly amongst these pseudo sites.
4) The inclusion of banked emissions in the vertical layers of the model will be determined on a case by case basis. UDAQ will confer with EPA to determine the most appropriate method to include these emissions in the model.

2.7.7 Inventory Quality Assurance

Quality assurance of the model-ready emissions inventory will be done by the emissions modelers. The tools used will be detailed reports of the SMOKE output that are created at each major step in the process. The level of detail that is now available via customized reporting tools allow for detailed analysis of process-specific inputs if needed.

In addition to the spreadsheet-style reports UDAQ also uses GIS tools to provide graphic analysis of the emissions database. The technical support documentation will include tables and geographic maps of the emissions inputs to the CMAQ model.

2.8 Model Input Quality Assurance Methods

MM5 and WRF data will be verified and quality assured using model performance bias and error statistics. Bias and error statistics will be computed for temperature, wind, and vertical atmospheric structure. We will look most closely at the model performance statistics in valley locations where elevated $PM_{2.5}$ is observed.

3. Model Performance Evaluation

UDAQ anticipates having model results for four past episodes during winter periods in 2007, 2008, 2009, and 2010. We will evaluate the model performance on all four of these episodes using the methods described in section 3.2 and 3.3.

3.1 Ambient air quality database

UDAQ's Air Monitoring Center maintains an extensive network of particulate and gaseous air monitoring sites. The monitor locations are located near and within populated cities and towns. In northern Utah, population is confined to the western front of the Wasatch Mountains and as a result Utah's air quality monitors are located linearly north to south along the Wasatch Front. Two notable exceptions are Tooele, Utah and Logan, Utah. Both of these locations are located in separate mountain valleys. The linear network of Utah's monitors will be an important factor as UDAQ follows EPA recommended modeling guidance and conducts $PM_{2.5}$ species interpolation and the "unmonitored area analysis".

UDAQ has developed the following air quality database with which the $PM_{2.5}$ SIP can be developed:

- Up to 17 Federal Reference Method (FRM) monitors (refer tables in section 2.5).
  - Between 4 and 7 daily monitors
  - Between 5 and 13 every third day monitors.
- Three Speciation Network (STN) sites.
  - One 1 in 3 day site.
  - Two every sixth day sites.
  - Two special studies where speciated data collected every other day.
- One URG Ambient Ion Monitor.
  - Continuous data available early 2010.
  - Special study data available in 2009.

- Four hourly ozone and pre-cursor monitors.

3.2 Evaluation Procedures

Base case model performance evaluation requires 3 main decision steps:

1. Identify a window of model grid cells to use for comparison with monitor.
2. Identify which window grid cell or window statistic to use for comparison with monitor.
3. Identify statistical performance measures.

Step1 and Step 2 are treated in section 3.0 of the EPA Ozone and $PM_{2.5}$ modeling guidance document with respect to the development of a model attainment test. Step 3 is treated in section 5.0 with respect to base case model performance evaluation. In UDAQ's judgment, it is appropriate to provide consistency between the methodology used to evaluate base case performance and the methodology used to evaluate attainment in the future. In the following text, UDAQ outlines EPA's suggestions from guidance section 3.2 for steps 1 and 2 described above and describes how UDAQ intends to formulate a model performance evaluation system appropriate for our domain.

3.2.1 Identify a Window of Model Grid Cells

EPA suggests that instead of using a single model grid cell to evaluate model performance a "window" of nearby cells should be used. EPA outlines 4 reasons why a window of model grid cells should be used:

1. Migration of predicted pollutant peak.
2. Intended spatial scale of monitor siting.
3. Model uncertainty provides leeway in predicted location of concentrations.
4. Misalignment of model grid cells and monitor location.

The guidance document defines cells "near" a monitor as cells located within a 15km radius of the monitor location. Table 3.2 in the modeling guidance indicates that the default recommendation for a 4km resolution modeling domain would be an array (window) of 7 cells x 7 cells (28km x 28km) with the monitor located in the center cell. EPA recognizes that the default definition of "near" may not be appropriate for all applications due to unique features of the modeling domain such as:

- Topographic features
- Mesoscale flow patterns
- Density of the monitoring network
- Density of emissions
- Other factors as appropriate

The definition of "near/nearby" (window size) can be changed to more accurately represent the unique features listed above provided an adequate justification is made.

Utah's modeling domain is unique for numerous reasons. Each of EPA's "unique features" described above is present in our modeling domain and necessitates a custom approach to defining the grid cell window. The default window size of 28km x 28km is far too large for use within our domain. Figure 3.1 shows the spatial relationship between topography, emission density, road networks, and monitor locations. Grid cell resolution is 4km x 4km. UDAQ believes that numerous justifications for using a non-default window size can be made following EPA's list of unique modeling domain features:

Topographic features: Utah's significant terrain is aligned north to south and controls the population distribution up and down the Wasatch Front. Use of a 28km x 28km window would draw in high mountain terrain that is far removed from elevated $PM_{2.5}$ concentrations.

Mesoscale flow patterns: Utah's non-attainment areas have numerous mountain canyons that create diurnal mesoscale flow patterns. In addition, the stagnant weather conditions that lead to elevated $PM_{2.5}$ concentrations typically feature very light and variable wind flow. The impact of these characteristics on predicted concentrations are more appropriately captured by a smaller window that captures near-monitor mesoscale conditions.

Density of the monitoring network: With few exceptions, the monitors within the UDAQ monitoring network are arranged in a linear fashion north to south along the Wasatch Front. A large and square grid cell window would encapsulate grid cells far from the near-monitor meteorological and emission conditions.

Density of emissions: The density of emissions is coincident with the population distribution and road networks of the Wasatch Front and Cache Valley. A large grid cell window would encapsulate grid cells with little to no emissions and would include grid cells in the mountains and over the Great Salt Lake.

To determine an appropriate window size UDAQ consulted a model domain map of road networks, monitor locations, topography, and emissions density. Figure 3.2 shows cell windows that capture the appropriate emissions density, uniqueness of monitor location, and representative valley topography. A 2 cell x 2 cell (8km x 8km) window appears to be appropriate for several reasons:

1) Limits grid cells to valley floors and does not include elevated terrain grid cells. This is especially important given the number of monitors located close to the eastern Wasatch Mountain benches.
2) Incorporates highest emissions density cells and eliminates low density cells. Outside of the Salt Lake Valley emissions rapidly fall off west of I15.
3) Identifies unique windows for most monitors. Many monitors are located in close proximity to one another and the smaller window allows unique windows to be identified for each monitor.

The 2 by 2 cell window will be the default window size selection for UDAQ, however, we plan on leaving the final window size selection flexible. For example, $PM_{2.5}$ speciation data shows very similar speciation across Salt Lake valley. This homogeneity combined with emissions

density distribution may allow for a larger window size. A larger window size would allow the model evaluation performance to consider predicted $PM_{2.5}$ that falls within the homogeneous Salt Lake Valley rather than limit predictions to the chosen 2 by 2 cell window.

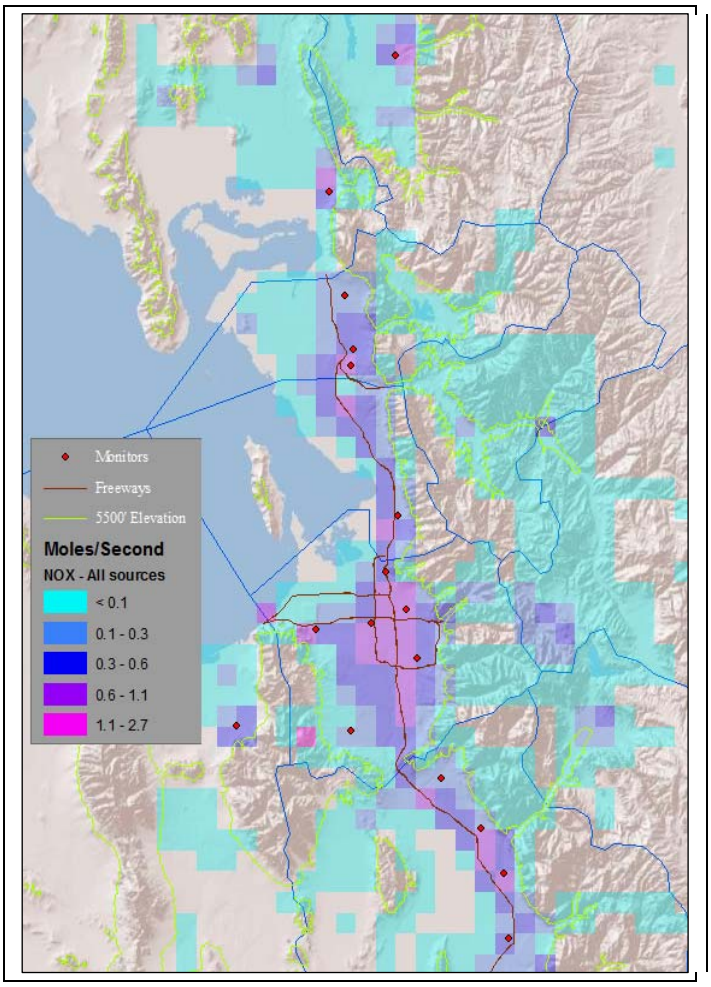

Figure 3. 1 Map used to identify custom model grid cell windows

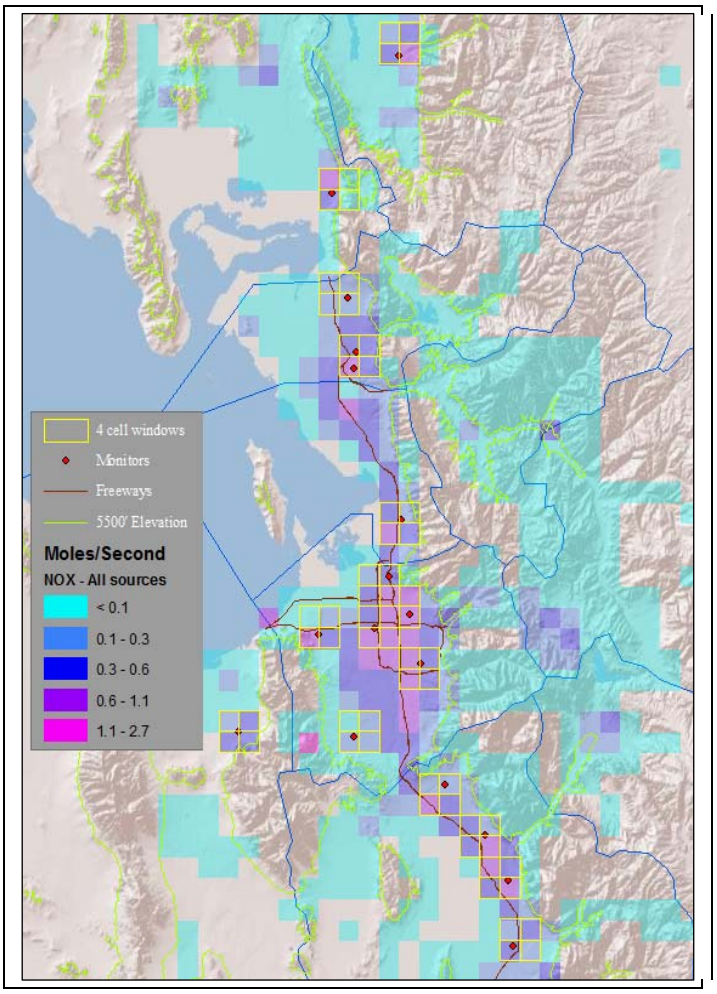

Figure 3. 2 Modeling domain with 4-cell windows

3.2.2 Identify a Window Statistic to Compare With Monitor

Based on prior and preliminary modeling experience, it is UDAQ's assumption that model concentrations will show an under-prediction relative to observed values. Provided that the model is under-predicting with accurate speciation percentages, UDAQ will likely select a window statistic that represents a mean value or higher. The range of possible statistic options are: mean of the window cells, 75th percentile of the window cells, and maximum window cell. It is difficult to determine the best statistic before model results are finalized, but the choice of model statistic(s) will be fully documented and explained in the Technical Support Documentation.

3.2.3 Performance Metrics and Tests

Chapter 18.0 of EPA's ozone and $PM_{2.5}$ guidance document provides guidelines on computing model performance metrics. UDAQ intends to closely adhere to the Boylan and Russel 2006 recommendations that are outlined in the guidance chapter by computing the following metrics

for 24 hour average total $PM_{2.5}$, 24 hour average $PM_{2.5}$ components, and appropriate hourly gas phase pre-cursor species:

- Mean Normalized Bias (MNB)
- Mean Normalized Gross Error (MNGE)
- Average Peak Prediction Bias and Error
- Mean Fractional Bias (percent)
- Mean Fractional Error (percent)
- Normalized Mean Bias (percent)
- Normalized Mean Error (percent)

Boylan and Russel 2006 indicate that the mean fractional error and bias are the most robust metrics for $PM_{2.5}$ model performance evaluation. They recommend a model performance goal of +50% and +/- 30% for mean fractional error and mean fractional bias. UDAQ will use these performance goals as targets, but they will not be considered as "bright line" cut-off points. These two metrics will form the core of our performance evaluation.

In addition, UDAQ will consider and compute whether other statistics included in EPA's Appendix A (root mean square error, correlation coefficients, etc) provide meaningful information for Utah's episodic $PM_{2.5}$ episodes. Numerous performance evaluation graphics will also be created including:

- Time-Series plots
- Scatter plots
- Soccer plots
- Bugle plots

UDAQ intends to compute these sets of statistics for all days of the $PM_{2.5}$ episode, but will also compute a separate set of statistics for days when the $PM_{2.5}$ is near or above the NAAQS standard. The performance statistics should be computed and weighted for days that represent conditions under which $PM_{2.5}$ forms rapidly. The ultimate goal is to reduce the formation of $PM_{2.5}$ and it is prudent to focus attention on the days when $PM_{2.5}$ forms rapidly versus days when $PM_{2.5}$ is low and even when $PM_{2.5}$ is high but diminishing.

3.3 Diagnostic Testing

Diagnostic testing of model performance will be extensive. Past and current experience with modeling winter inversions in intermountain valleys has shown that replicating inversion dynamics is a difficult task for meteorological models. The EPA modeling guidance explains the importance of diagnostic testing as a means to check the model's estimate of $PM_{2.5}$ in response to changes in precursor emissions. The results of these tests can provide confidence in the model's ability reflect changes in pollutant concentrations that would be expected from control strategy implementation. Section 18.5 of the guidance document suggests five possible approaches with an explanation of each technique as well as caveats about the interpretation of results.

- Observational models
- Probing tools

- Receptor models
- Retrospective analyses
- Sensitivity analyses

The first and last of these tests are the ones that will most likely be used for this analysis. UDAQ does not have receptor model capability and a retrospective analysis will not be possible during the time available to create the SIP. The limited use of probing tools may be useful to UDAQ during the evaluation period using process analysis tools that we have some limited experience with. However, the other technique mentioned, that of source apportionment, is not available in the current version of CMAQ from the CMAS modeling center.

The use of observational models, as described in the guidance, is dependent on the availability of measurements of important precursor compounds during the modeling episodes. UDAQ has access to limited data sets that might be of use for such an analysis; in fact, we have done some of that type of performance testing already. We intend to use whatever data is available to help us to understand the model's capability to respond to changes in emissions inputs. In this context, we feel that the use of refined, emissions sensitivity testing will also provide insight into the model's handling of secondary pollutant formation.

3.4 Modeled Attainment Test Using the Modeled Attainment Test Software (MATS)

The MATS program is designed to perform two basic analyses of future year modeling.

1. Interpolate the species fractions of the PM mass from the STN monitors to the FRM monitors. The model also calculates the relative response factor (RRF) for grid cells near each monitor and uses these to calculate a future year design value for these cells.
2. Perform an unmonitored area analysis on grid cells in areas of the domain that are far from monitors. This is done by adjusting the modeled values in grid cells with the observed values from monitors in the domain. The adjustment is based on an inverse distance weighting so that monitored data nearest to a grid cell exerts the most influence in the adjustment. The capability to perform an unmonitored area for daily average $PM_{2.5}$ is ***not*** currently implemented in MATS.

UDAQ will use MATS for the modeled attainment test at grid cells near monitors (number 1, above). It was noted in comments by EPA Region 10 that, given the distance and terrain barriers between Logan and the Wasatch Front, interpolating speciation profiles between these two locations is problematic. UDAQ shares this concern. Referring to the discussion of Table 1.2 on pages 9 and 10 of this document it seems probable that a MATS interpolation would probably not present a problem. This is because the ratios of the major components of $PM_{2.5}$ are quite similar among all of the monitors from Utah County in the south to Cache County in the north.

MATS uses the SANDWICH method to reconcile the differences between data collected using the FRM and CSN monitors. Given the fact that we have only 3 speciation monitors, we do not have alternative data sets on which to draw for an alternate speciation profile for the subset of our FRM monitors that are located at a distance from the CSN monitors . For this reason we believe that the most appropriate course is to use the MATS-interpolated speciation profiles for all of the monitors in our domain.

Also, please keep in mind that the modeled attainment test uses speciated *design values* which are themselves an average of five years worth of data. There is an inherent smoothing of the data with this method. While this smoothing does not relate to the large geographic distance between some of the monitors and the three CSN sites, the fact remains that there is simply no other data available to perform alternate analyses.

3.4.1 Future Year Modeling

UDAQ will perform a model performance evaluation on all 4 episodes. Each episode that meets performance criteria (criteria are outlined in section 3.4.1) with support from supplemental analysis will be used for future year modeling. Based on our years of modeling experience, UDAQ feels that it is possible that one or more of the selected episodes may not meet performance criteria due to the inability of MM5/WRF to capture Utah's unique cold pools. In this situation UDAQ will consult with both EPA Regions and the State of Idaho to determine if the performance criteria can be relaxed on a case-by-case basis.

It is possible that EPA will release a version of MATS sometime in 2011 that will be capable of an unmonitored area analysis for daily $PM_{2.5}$. The issues of a clustered set of observation data, as opposed to an evenly distributed network of data point throughout the domain will still remain. In addition, significant terrain barriers that impose physical constraints on a simple distance-weighted spatial interpolation scheme pose real limitations on the theoretical validity of such an interpolation. As stated above, UDAQ will consult with the technical group from EPA and the State of Idaho to decide how to address this issue.

3.4.2 Unmonitored Area Analysis Outside of MATS

As noted in the previous section, the next version of MATS will include the ability to perform an unmonitored area analysis for daily $PM_{2.5}$. However, MATS is not presently capable of this analysis and for that reason we are proposing a method for an unmonitored area analysis that is similar to MATS but without the spatial interpolation. If a new version of MATS is released during the evaluation period of the $PM_{2.5}$ SIP, that version of MATS will be used to do the unmonitored area analysis for the 24-hour-average $PM_{2.5}$ attainment test.

UDAQ does not view the absence of interpolation as a weakness in this proposal because there is not a sufficient observation network to do a credible spatial interpolation whether or not one uses MATS. Because of the sparse observational data greater weight will be placed on our air quality modeling in this analysis. The modeled data in the unmonitored areas will be anchored to the observations by calculating a model bias for individual monitors representing different air basins in the domain.

First, the modeling domain will be separated into five different regions within the modeled attainment test area shown in Figure 2.2. For example, the Logan monitor will solely be used for extrapolating $PM_{2.5}$ information to all of Cache Valley. Likewise the Toole monitor will be utilized for Toole County. The unmonitored region of Box Elder and Weber counties might be an average of the stations in those two counties. Utah County will use the monitors in that county and the area surrounding Salt Lake and Davis counties will be based on the monitors in

those areas. This approach will create a more accurate representation of the state's distinct air basins.

The next step is to create model-bias factor for each of the four air basins. The goal here is to have one bias factor for each individual air basin. This is done using a two step method:

1. Modeled 24-hr values in the four grid cells surrounding each monitor will be averaged over the top 10% of $PM_{2.5}$ concentrations for each episode.
2. From observational data, base year design values are calculated in MATS. A bias factor is created by dividing the base year design value by the value calculated in step 1.

This bias factor is then multiplied by the future year $PM_{2.5}$ estimates for each grid cell within the air basin. For example, if the base year design value is 20% larger than the model derived base year estimate near that monitor, then all future year $PM_{2.5}$ in the unmonitored area of the air basin will be multiplied by 1.2. This bias correction is done in order to make the future year modeling results more realistic.
The final step is to create the future year design value for each grid cell in the unmonitored area. In each grid cell $PM_{2.5}$ will be averaged over 10% of the days during the episode corresponding to the highest $PM_{2.5}$ values. This becomes the future year design value and is compared against the NAAQS for each cell within the unmonitored area.

The method described above applies to air basins that have only one $PM_{2.5}$ monitor. If an air basin has more than one monitor the bias factor will be calculated as an average of each individual bias factor in the air basin.

4. Supplemental Analyses

EPA modeling guidance requires that a SIP include significant additional analyses in conjunction with the model attainment test. The purpose of the additional analyses is to reduce the uncertainty associated with a model only approach. EPA provides guidance on numerous possible additional analyses that can lend support to the modeled demonstration.

Of particular interest are analyses that help determine whether the model likely over-predicts, under-predicts, or accurately predicts the air quality improvement projected to occur by the attainment date. EPA describes three basic types of supplemental analyses that are recommended to supplement the primary modeling analysis. They are:

1) Additional modeling
2) Analyses of trends in ambient air quality and emissions
3) Observational models and diagnostic analyses

In addition to this "primary" modeling analysis, EPA lists various other models, applications, and tools that can be used to supplement the results of the modeled attainment test. These include, but are not limited to:

1. Use of available regional or national scale modeling applications that are suitable for the local area.

2. Use of other appropriate local modeling attainment demonstrations that include the non-attainment area of interest.
3. Use of photochemical source apportionment and/or process analysis modeling tools to help explain why attainment is (or is not) demonstrated.
4. Use of multiple air quality models/model input data sets (e.g., multiple meteorological data sets, alternative chemical mechanisms or emissions inventories, etc.). For results to be most relevant to the way we recommend models be applied in attainment demonstrations, it is preferable that such procedures focus on the sensitivity of estimated relative response factors (RRF) and resulting projected design values to the variations in inputs or model formulations.
5. Use of dispersion models to address primary $PM_{2.5}$ contributions to monitors. In areas with large spatial gradients of primary $PM_{2.5}$, dispersion models are best suited to characterizing the change in primary $PM_{2.5}$ in the future. Areas that are relying on local primary PM controls to reach attainment should submit a local area analysis as part of the primary attainment demonstration. In other areas, a local area analysis may be useful as a supplemental analysis.
6. Application of the attainment test with alternative procedures compared to the default recommendations in Sections 3, 4, and 5 of the guidance. Any alternate approaches should be accompanied with a technical justification as to why the approach is appropriate for the area in question and should be discussed with the appropriate EPA regional office.

UDAQ Supplemental Analysis Plans

UDAQ believes that the greatest $PM_{2.5}$ modeling challenge is directly related to how well the meteorological modeling can reproduce the strong stability and light winds that trap pollution in Utah's non-attainment areas. To that end, UDAQ plans to concentrate supplemental analyses on meteorological model uncertainty evaluation. Fortunately, Utah's $PM_{2.5}$ problem results from stagnation and trapping of local emissions and does not depend on long range transport. The fact that local emission mixes are consistent from day to day and are input into stagnant terrain trapped air (the bathtub effect) presents an ideal opportunity to apply observation based analyses of key $PM_{2.5}$ precursor emissions. To this end, UDAQ has identified 4 supplemental analyses that will focus on "Additional modeling" and "Observational models and diagnostic analyses":

4.1 Additional Analyses to Corroborate Modeled Attainment Test

Additional Modeling

1) Multi-Episode Modeling:

UDAQ's episode selection process identified 4 periods of elevated $PM_{2.5}$ concentrations during 4 different winter seasons. Three of the four periods constitute single $PM_{2.5}$ event episodes consisting of between 7 and 20 days. The modeling period from the winter of 2009-10 consists of 5 unique $PM_{2.5}$ event episodes that occurred over the course of 45 days. The diversity of modeling 8 $PM_{2.5}$ episodes modeled will serve as a robust base from which to evaluate attainment strategies. Furthermore, the meteorological modeling of the 4 periods (8 episodes) includes many model configurations including a 30 member MM5/WRF ensemble for the 2008 episode and a variety of physics and FDDA options applied to the 2009-2010 episode. The diversity of episodes and model configurations will provide valuable information regarding the impact of meteorological modeling on

concentration predictions. The number of selected episodes for modeling represents an effort above and beyond that which is normally required for a SIP demonstration. UDAQ has included these episodes in the modeling protocol. However, they were selected specifically for the purpose of providing supplemental analyses.

2) Ensemble Meteorological modeling:

The modeling period in February 2008 was conducted in conjunction with the National Center for Atmospheric Research (NCAR) and Dugway Proving Ground. NCAR developed a 30 member MM5 and WRF ensemble model data set for UDAQ to evaluate the sensitivity of CMAQ $PM_{2.5}$ production. In addition, UDAQ in-house WRF modeling will test physics options, initialization options, grid nudging, and observation nudging for their impact on CMAQ modeled chemistry. As in number 1 above, the ensemble modeling was selected at the outset for the primary purpose of evaluating meteorological model uncertainty on CMAQ predictions and thus providing a supplemental analysis.

3) Ensemble emissions modeling:

UDAQ will develop a small set of ensemble emissions inventories for evaluation of CMAQ emissions related uncertainty. The emission inventory "members" will each reflect adjustments to one or more portions of the inventory in order to treat the uncertainties that are associated with the inventory. For example, one member might reflect uncertainty associated with area source VOC emissions. It is likely that the base-line are inventory has uncertainty bars of +/- 20% so the member would simply be assuming that it is equally likely that the area source VOC inventory is base-line, +20% from base-line or -20% from base-line. In this way, we can gain (or reduce) confidence in the attainment test conclusions.

4) Trends:

UDAQ will produce an emissions trends analysis in order to evaluate the direction of $PM_{2.5}$ precursor emissions. A trends analysis of $PM_{2.5}$ concentrations will not be conducted because past attempts at producing such an analysis have been confounded by the controlling impact of seasonal weather patterns. A concentration analysis would only produce uncertainty and would not be helpful as a supplemental analysis.

4.2 Weight of Evidence Determination

In the event that model results and performance tests require a "Weight of Evidence" (WOE) submittal DAQ has identified 2 main sources of supporting data. The data is based on observation studies commissioned by DAQ.

Observational models and diagnostic analyses

1) Brigham Young University chemistry study Winter 2009:

Speciated $PM_{2.5}$ data show that NH4NO3 constitutes between 50% and 75% of total observed $PM_{2.5}$. NH_4NO_3 is known to form through a reaction between HNO_3 and NH_3.

Consequently, the control of HNO_3 production will likely be a critical component of a successful attainment demonstration. What is not known is if the majority of HNO_3 production occurs during the day, during the night or if HNO_3 production is limited by a precursor. To this end, during the winter of 2009 UDAQ funded a $PM_{2.5}$ study aimed at identifying the dominant HNO_3 production pathway. Results from the study indicate that NH4NO3 is limited by HNO_3 production and there was some evidence that HNO_3 is most actively produce during the daytime, however, the results are somewhat inconclusive and UDAQ will investigating further (see below). A journal paper has been submitted with the results of this study (*Kuprov, 2010).*

2) URG Ambient Ion Monitor data:

During the late winter of 2009-2010 UDAQ purchased a URG ambient ion monitor in order to measure HNO3 and other $PM_{2.5}$ precursors. This instrument is combined with real-time ambient NH3 and organic carbon monitors. A small set of URG data was collected during the late winter while the URG was undergoing testing and setup. UDAQ fully expects that during the winter of 2010-11 a significant set of data will be collected that will provide robust information related to the formation of HNO3 and the behavior of organic carbon. UDAQ believes that this data will be critical identifying limiting NH4NO3 precursors and to evaluating and corroborating model response to emission control strategies.

4.3 Large Point Source Incremental Modeling

Section 5.3 of the EPA modeling guidance suggests that in some cases it may be appropriate to perform dispersion modeling on large sources of primary PM2.5 to determine whether such sources may impact an exceedence of the NAAQS. However, in an area such as northern Utah where the main species of PM are not primary but secondary components the guidance is not clear on specific recommendations.

After discussions with EPA Region 8 concerning the nature of the PM2.5 problem in Utah and Idaho, as indicated by the speciated monitors, it has been decided to forgo this analysis. EPA and UDAQ agree that this issue and may be revisited in the future if such an analysis appears to be necessary. In addition, if EPA does establish modeling guidance that relates more directly to the conditions in northern Utah, UDAQ and EPA Region 8 will revisit this issue in light of the updated modeling guidance.

5. Procedural Requirements

5.1 Plan for Archiving Technical Data

The air quality modeling system consists of three major components:

- Emissions processor
- Meteorological model
- Photochemical air quality grid model

All of the data sets related to these activities, as well as the model code for each process, are housed with multiple backups on the UDAQ Linux computer network.

A set of spreadsheets which detail model inputs and sensitivity test options for all of the episodes and all of the model runs are maintained on a Google account for that purpose.

5.2 List of Deliverables

As a part of the technical support documentation for this modeling analysis UDAQ will provide the following documentation.

- Database of all model runs completed, including meteorological and emissions inputs used.
- Report on model performance evaluation for all episodes
- Emission inventory reports and graphic analysis of base year, future year, and control strategy inventories
- Graphical and statistical analysis of meteorology model performance evaluation
- Graphical and statistical analysis of air quality model performance evaluation

6. References

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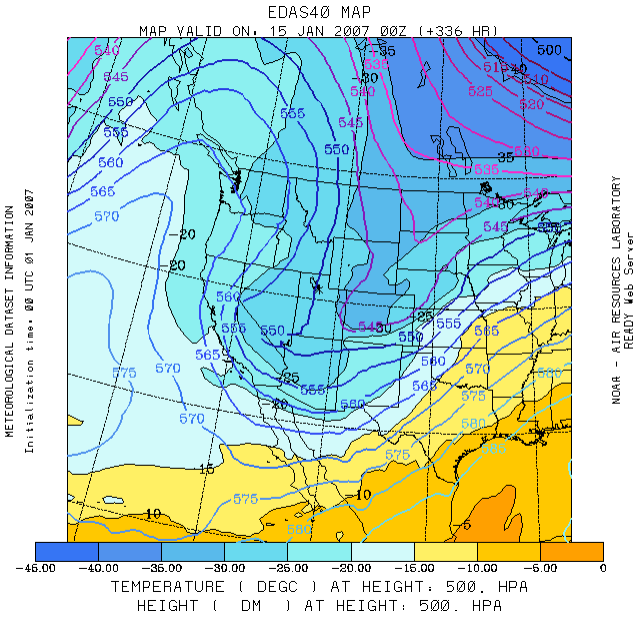
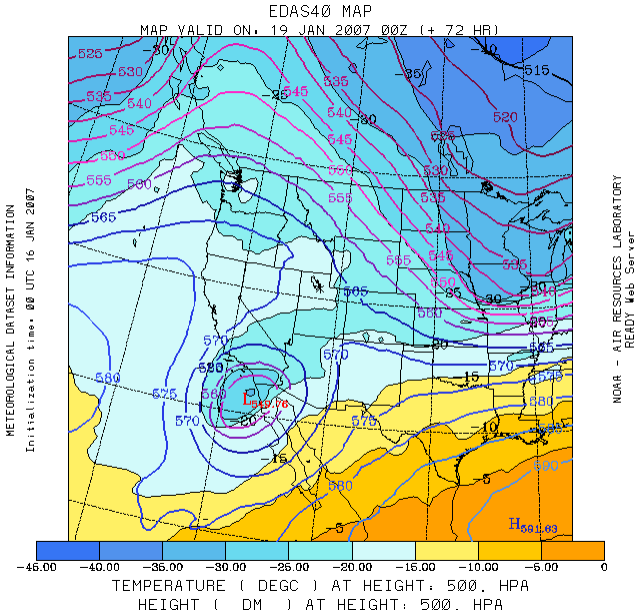
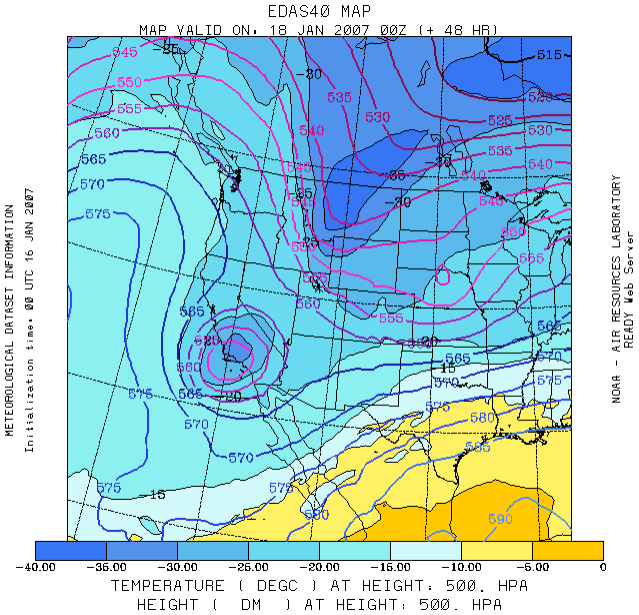
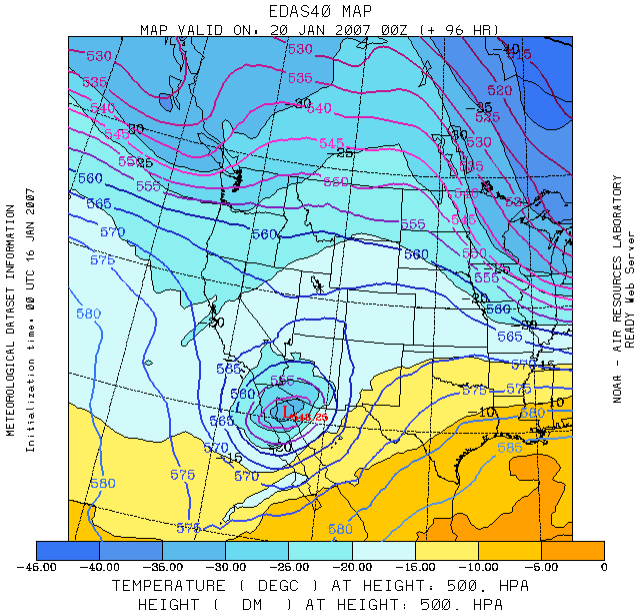
Appendix 2.1 – 2007 500mb Maps

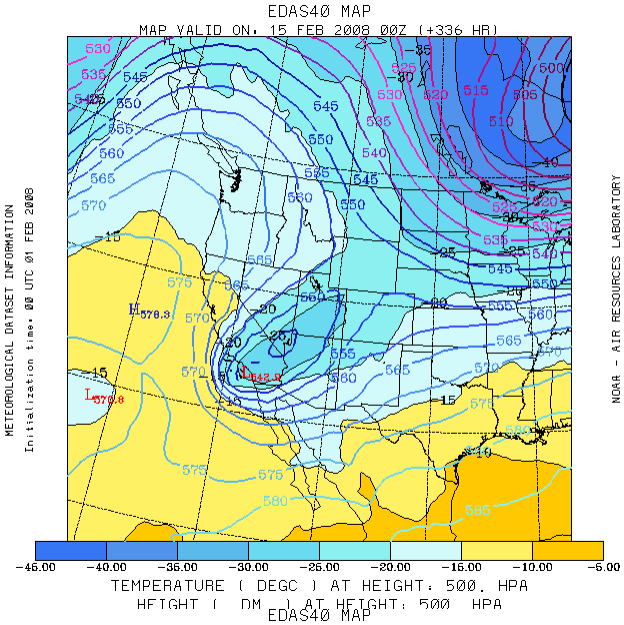


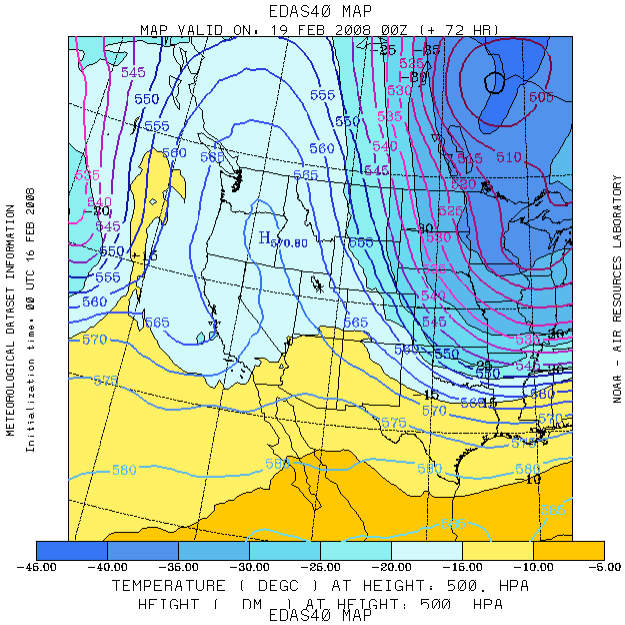


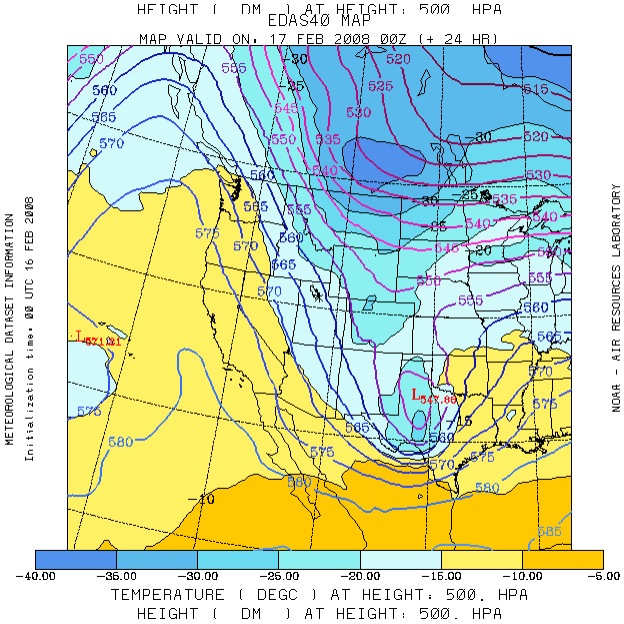


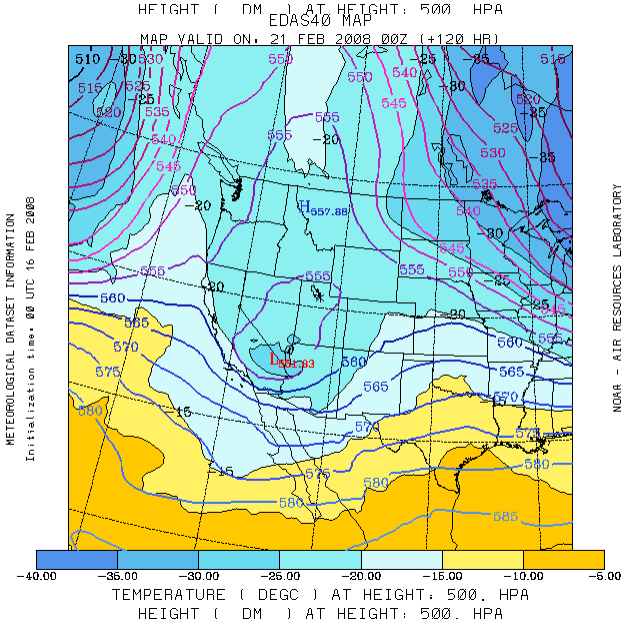


Appendix 2.2 – 2008 500mb Maps

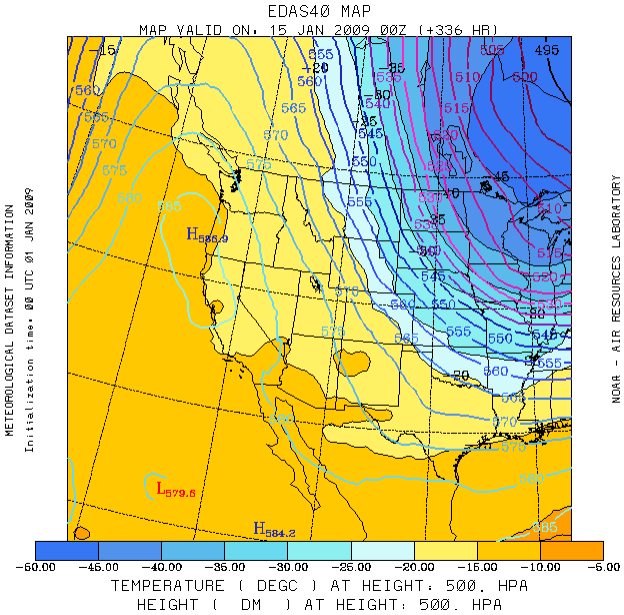


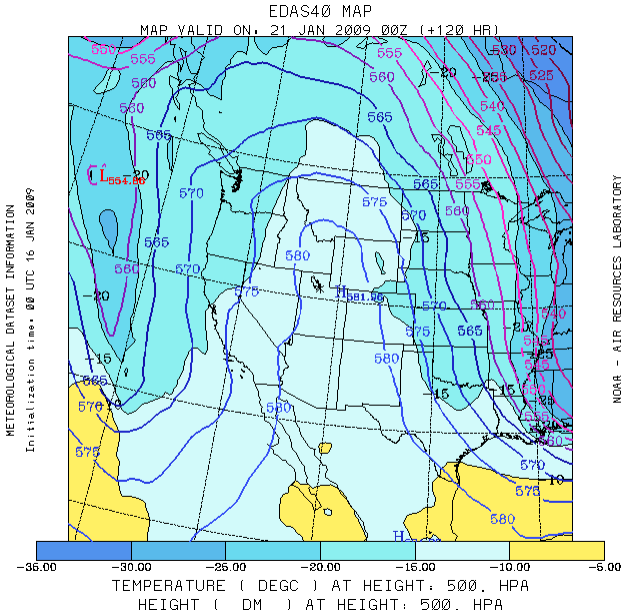


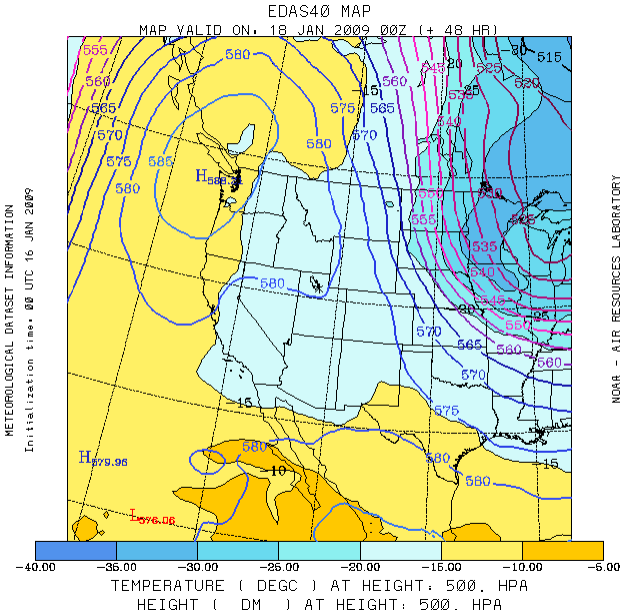


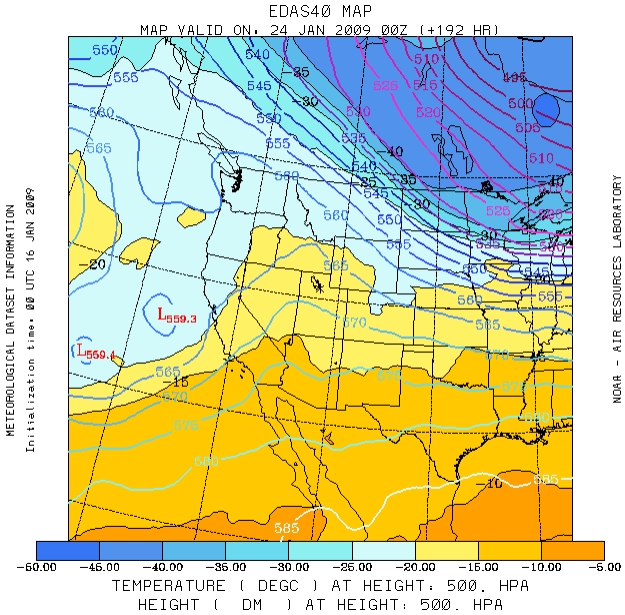


Appendix 2.3 – 2009 500mb Maps



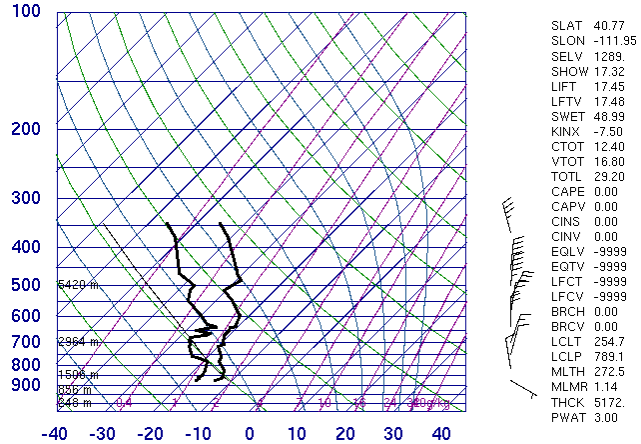






Appendix 2.4 – 2007 Soundings

72572 SLC Salt Lake City



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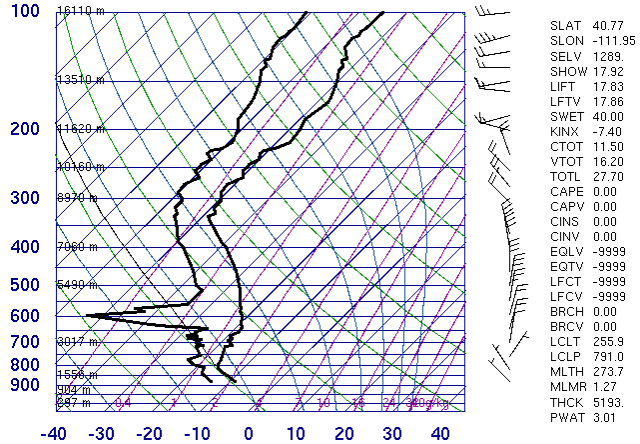

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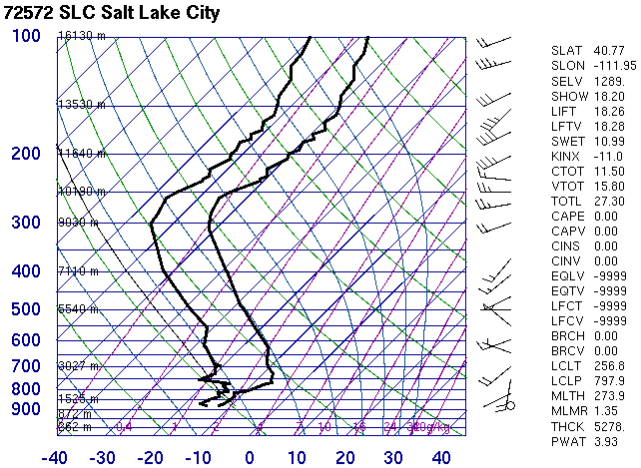
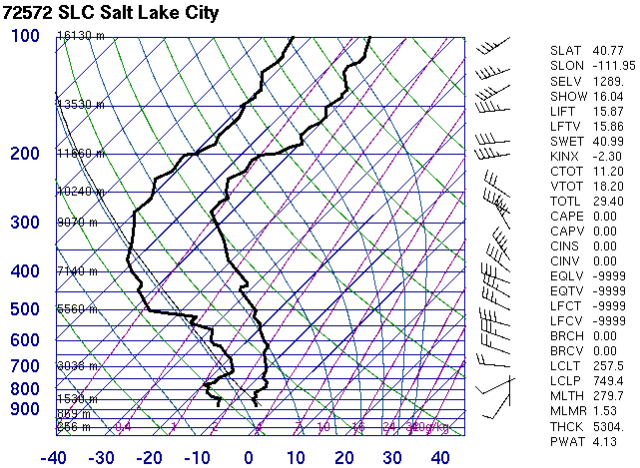


12Z 17 Jan 2007 University of Wyoming

72572 SLC Salt Lake City



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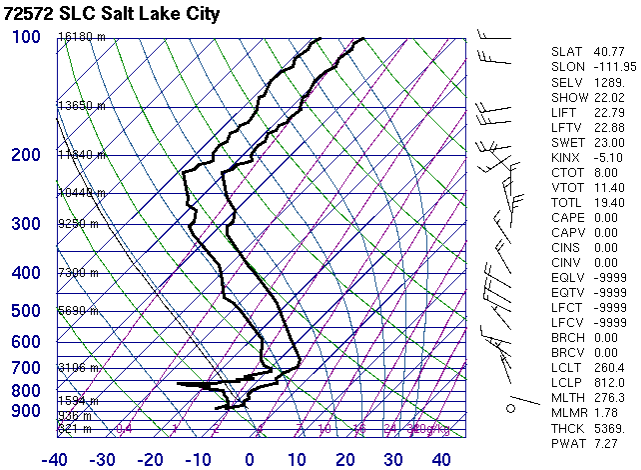
72572 SLC Salt Lake City



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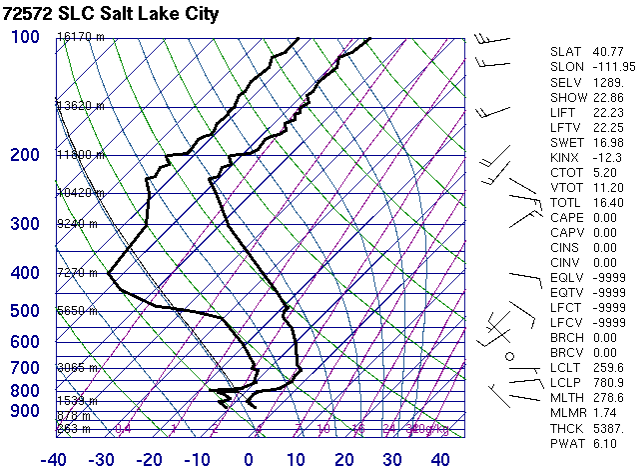

00Z 20 Jan 2007 University of Wyoming

Appendix 2.5 – 2008 Soundings

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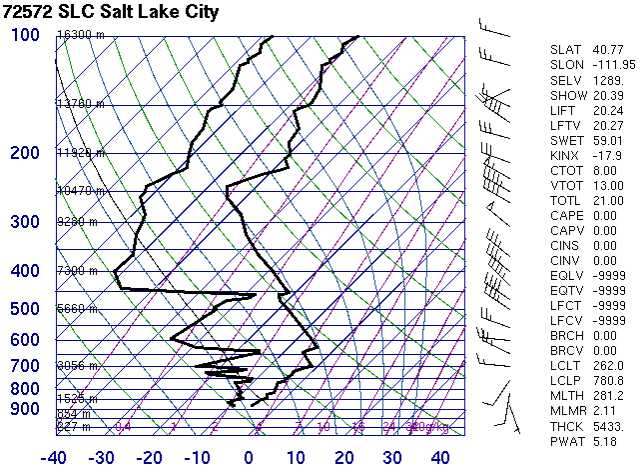
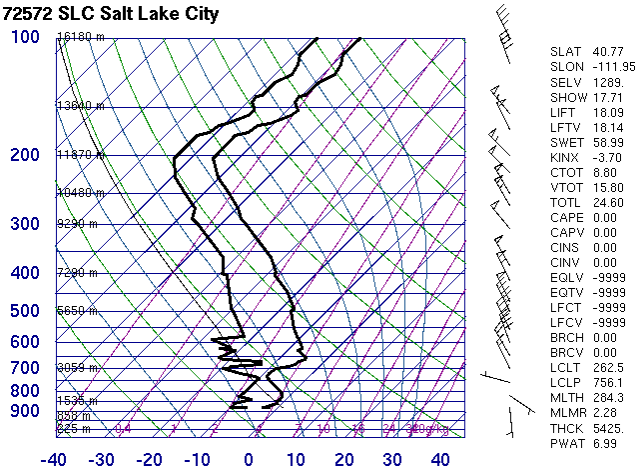


12Z 16 Feb 2008 University of Wyoming

72572 SLC Salt Lake City



12Z 18 Feb 2008 University of Wyoming

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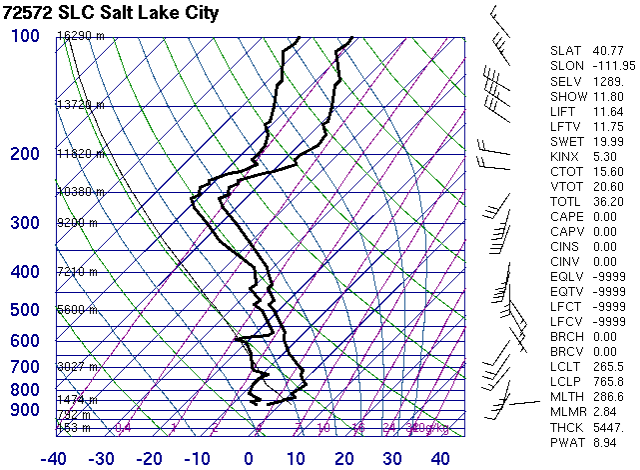

12Z 20 Feb 2008 University of Wyoming

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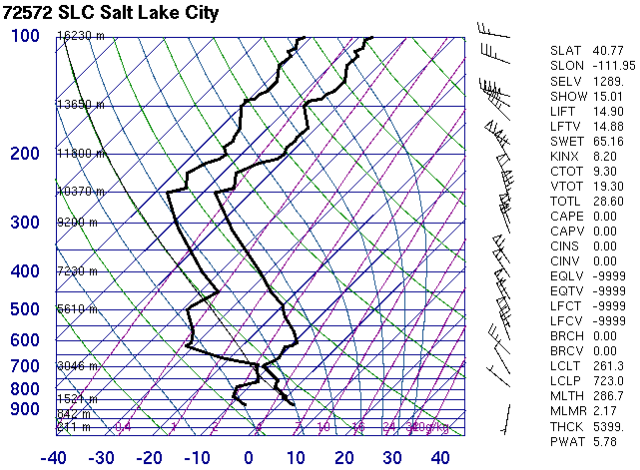

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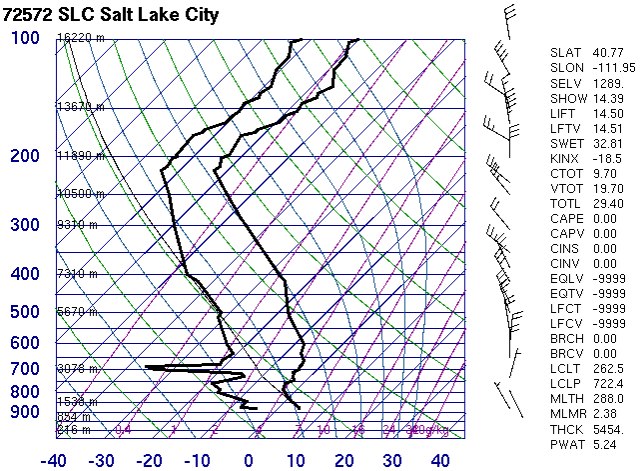

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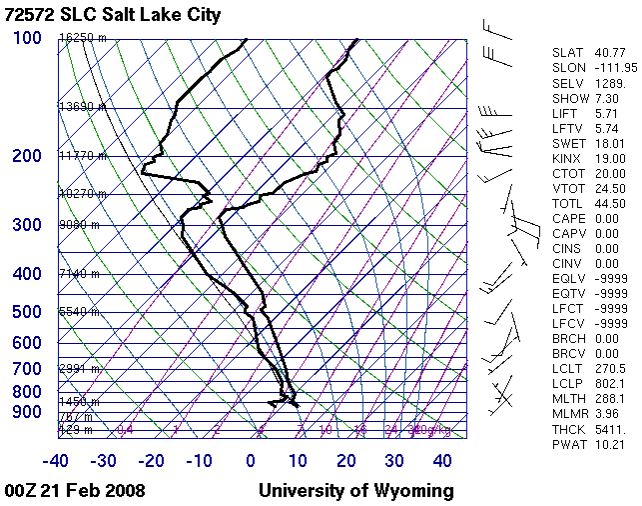
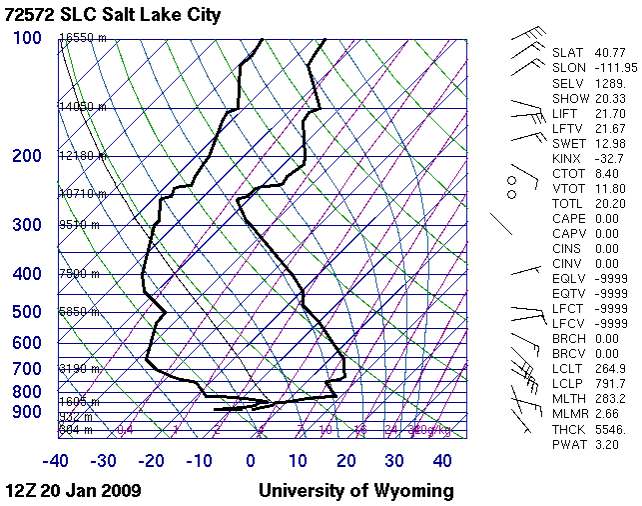
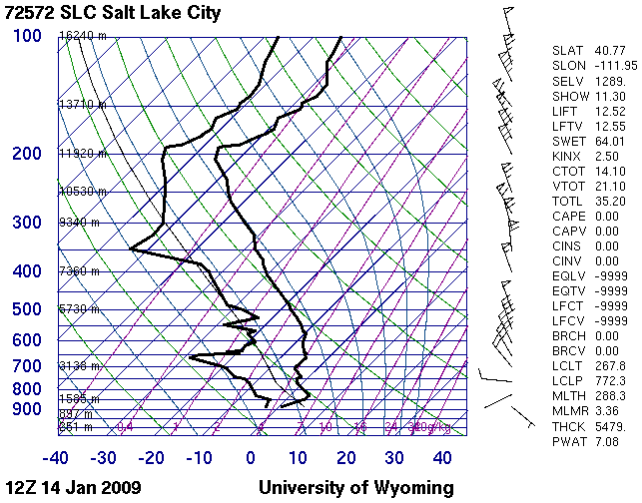
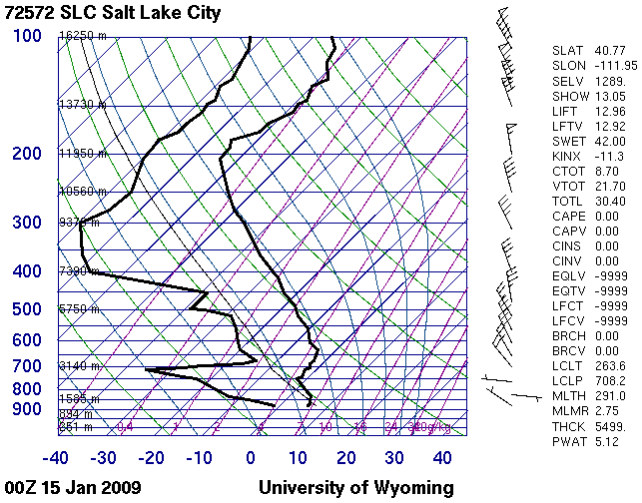
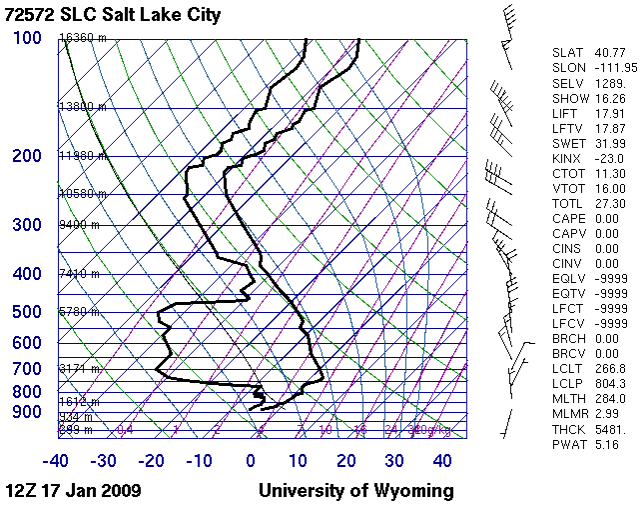


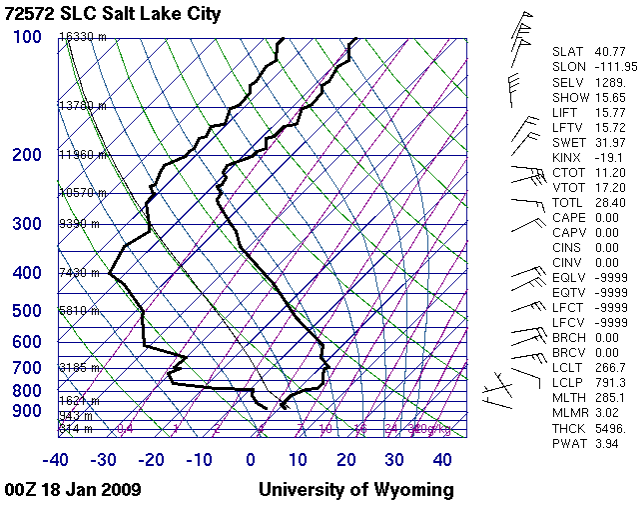


Appendix 2.6 – 2009 KSLC Soundings

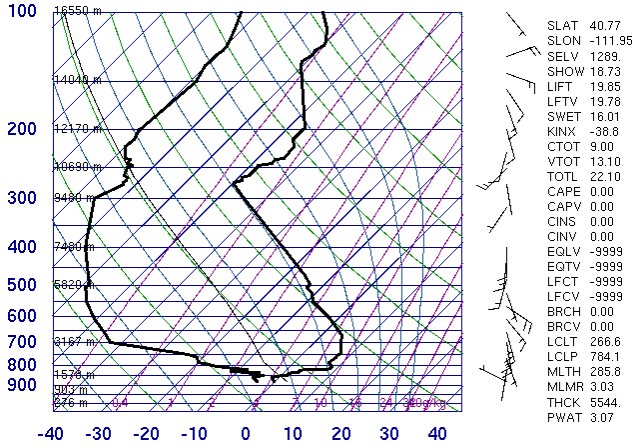








72572 SLC Salt Lake City



00Z 21 Jan 2009 University of Wyoming

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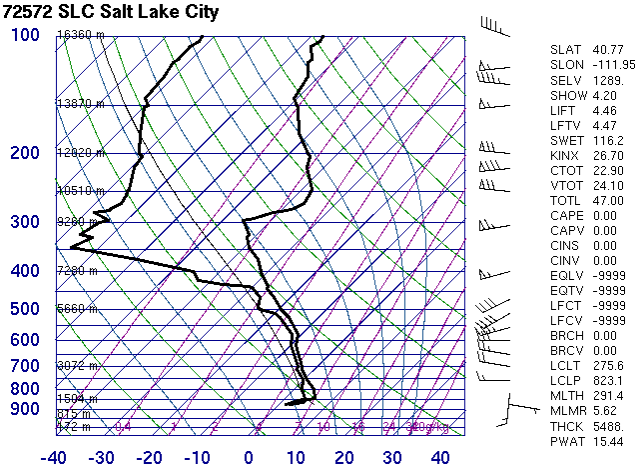

12Z 23 Jan 2009 University of Wyoming

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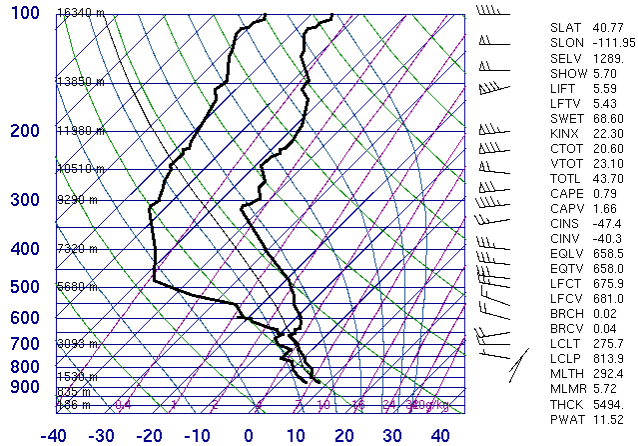

00Z 24 Jan 2009 University of Wyoming

Appendix 2.7 – Monitoring Locations

BR	Brigham City, Utah
L4	Logan, Utah
BT	Bountiful, Utah
CW	Cottonwood, Utah
N2	North Salt Lake, Utah
MG	Magna, Utah
HW	Hawthorne (Salt Lake City), Utah
WV	West Valley, Utah
HE	Herriman, Utah
T3	Tooele, Utah
NP	North Provo, Utah
LN	Lindon, Utah
HG	Highland, Utah
SF	Spanish Fork, Utah
O2	Ogden, Utah
WT	Washington Terrace, Utah
NOG	North Ogden, Utah
FRK	Franklin, Idaho