PM$_{10}$ MAINTENANCE PLAN MODELING PROTOCOL
SALT LAKE COUNTY, UTAH COUNTY & OGDEN CITY

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July 21, 2004

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1.0 INTRODUCTION

The State of Utah is in the process of preparing a Maintenance Plan for the Salt Lake County, Utah County and Ogden City PM_{10} nonattainment areas. The PM_{10} Maintenance Plan Modeling Protocol provides the context for the modeling in the PM_{10} Maintenance Plan, discusses the characteristics of the PM_{10} problem in the Wasatch Front, and outlines the modeling process which the Utah Division of Air Quality (DAQ) intends to use in addressing these PM_{10} issues.

1.1 Background

The State of Utah developed two (Salt Lake County and Utah County) State Implementation Plans (SIP)s for PM_{10} in the early 1990's. These SIPs were approved by EPA in 1994, and targeted Utah's historical problem with secondary particulate formation during wintertime inversions along the Wasatch Front. In 2002 a revised SIP was submitted to EPA for Utah County as a result of their inability to show conformity in 2000. A SIP for Ogden City has never been put in place, although the State is working with EPA to use the Clean-Data approach to meet the requirements of §110 of the Clean Air Act. No violations of the NAAQS in the nonattainment areas during winter-time inversion events have been recorded since the SIPs in Salt Lake and Utah Counties were originally implemented. Therefore, DAQ plans to submit a Maintenance Plan to redesignate Salt Lake County, Utah County and Ogden City as attainment areas.

In consultation with EPA Region VIII, DAQ has decided to base the attainment demonstration for this new Maintenance Plan on a grid-based aerosol modeling approach using UAM-AERO. UAM-AERO is an urban-scale grid-based aerosol model developed by the California Air Resources Board. The model will be used to analyze the airshed for two characteristic wintertime inversion episodes that occurred in 2001 and 2002. DAQ believes that these episodes represent meteorology that is characteristic of exceptionally severe wintertime inversion events. Furthermore, both of the episode's emissions inventories are representative of the emissions currently released into the nonattainment areas. Therefore, modeling these episodes and projecting the emissions to future years should accurately represent the ability of the nonattainment areas to maintain the PM_{10} NAAQS over the next 10 years. Data availability during 2001-2002 is much improved over earlier modeling efforts DAQ has conducted. This should improve confidence in model performance over past efforts. Since aerosol modeling is still in its infancy, relative to photochemical ozone modeling, guidance on model performance evaluation is not available. For this reason UAM-AERO may be used in a relative sense only.

1.2 Objectives

The State of Utah is required to develop a plan to demonstrate that it is able to maintain ambient air quality conditions for PM_{10} below the federal 24-hour standard for specific years in the future for the Salt Lake County, Utah County and Ogden City nonattainment areas. To meet the goals of this study DAQ will complete the following tasks: 1) develop an emissions inventory, 2) develop high-resolution meteorological fields, and 3) complete modeling analysis of input and output data sets. DAQ will provide the modeling expertise for the general development and running of UAM-AERO through a multi-phased effort to apply an aerosol grid model to the Wasatch Front area.

This protocol documents the activities associated with conducting the PM_{10} modeling for winter time inversion episodes and evaluating the model's performance prior to its use in demonstrating future maintenance of the PM_{10} NAAQS. A subsequent addendum to this protocol will be prepared, if needed, to provide more specific information on the methodologies for estimating control strategy requirements, procedures for maintenance demonstration, and associated documentation and submittal requirements.

1.3 Choice of Models

It is recommended that the UAM-AERO employing CB-IV chemistry be used as the aerosol model in the PM_{10} Maintenance Plan modeling. UAM-AERO is an extension of the widely used photochemical model, the Urban Airshed Model (UAM), Version IV, which has been adapted to treat aerosol processes. DAQ chose to use this model because of extensive staff experience using UAM-AERO for the recent Utah County SIP and because the chemical mechanism in UAM-AERO has been tested more extensively than for other models (Seigneur and Pai, 1999). The key feature of the UAM-AERO model is that it provides a common framework in which to evaluate relationships between ambient concentrations of both ozone and particulate matter (PM), and their precursor emissions (Kumar and Lurmann, 1996; Lurmann, et al, 1997).

Given the complexity of the local mountainous terrain, in close proximity to two large bodies of water (Utah Lake and Great Salt Lake), DAQ recommends the use of high-resolution meteorological observations in combination with the Diagnostic Wind Model (DWM) and the Atmospheric Boundary Layer Model (ABLM) to develop the meteorological inputs to the UAM-AERO. DAQ will complete this process.

Processing of the emissions data sets assembled for point, area, and mobile sources will be accomplished through use of the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system. This emissions handling system was developed by EPA for integration into the Models-3 Air Quality Modeling System. Because wintertime episodes will be modeled, estimates of biogenic emissions will not be included in the analysis.

1.4 Overview of the Modeling Project

Major inversion episodes (stagnant conditions persisting for one to three weeks) occurred during the 2001 and 2002 winters in the Wasatch Front urban area. These inversions were similar to inversion periods that occurred in 1996 and in the late 1980s. Despite the presence of strong and persistent inversions during the winters of 2000-2002, Wasatch Front PM_{10} values have not exceeded the NAAQS since 1996 during wintertime inversion events. The PM_{10} NAAQS has been exceeded at 2 locations during non-inversion related wind events associated with Kennecott's Tailings Pond and July 4th fireworks celebrations. These "special" event exceedences have been flagged as exceptional events by the DAQ. It is during stagnant conditions that PM_{10} builds up in the area and as the condition persists, more and more PM_{10} (especially secondary PM) accumulates causing elevated ambient levels. The fact that the NAAQS have not been exceeded in recent years during winter-time inversion events, indicates that emissions improvements in the airshed have provided the necessary changes to meet the PM_{10} NAAQS during winter-time inversion episodes.

1.5 Schedule

The current schedule for the PM_{10} Maintenance Plan modeling development is as follows:

Activity	Date
Final Base Year Emissions Inventory Complete	December 15, 2003
Future Year Emissions (Growth + Mandatory Controls) Complete	April 15, 2003
Submit Draft Modeling Protocol to EPA	May 1, 2003
Preliminary Base Year Emissions Inventory Complete	July 15, 2003
Meteorological Inputs Complete	August 15, 2003
Base Case Model Runs and Model Validation Complete	September 15, 2003
Model Future Year (Growth + Mandatory Controls) Complete	January 1, 2004
Future Year Emissions for Control Strategies Complete (if necessary)	May 15, 2004
Model Future Year including Control Strategies (if necessary)	May 15, 2004
Submit Final Modeling Summary Report to EPA	August 15, 2004

1.6 Protocol Structure

The structure of this protocol follows EPA's "Guidelines for Regulatory Application of the Urban Airshed Model" (EPA, 1991). Section 2 summarizes current knowledge of the air quality and meteorology of the Wasatch Front area as it influences PM_{10} episodes. Section 2 also identifies the recommended modeling episodes and the modeling domain. The methodology for developing emissions estimates for use in aerosol modeling is described in Section 3; similarly, Section 4 discusses the methodology for developing the meteorological inputs to the model. Section 5 discusses the methodology for developing inputs to the aerosol model as well as details of the aerosol model itself. While every attempt has been made to thoroughly describe the recommended methodologies, there are obviously some details and decisions that cannot be prescribed at this time. Important modeling issues that arise throughout the input preparation process will, of course, be discussed with EPA representatives as appropriate.

Section 6 lays out the procedure recommended for evaluating the performance of the aerosol model. Evaluation criteria will be negotiated with EPA Region VIII and will reflect the best understanding available for evaluating model performance. Also discussed in section 6 are some of the diagnostic analyses (e.g., model sensitivity simulations) to be carried out with the emissions, meteorological, and air quality models in order to develop a reliable system of models and data bases.

Once the modeling system has been evaluated and judged ready for control strategy evaluation, it will be used to explore future-year emissions scenarios. A discussion is included of the general procedures that have been used in the past for adjusting base-year emissions and other model inputs to reflect desired future-year conditions. These are outlined in Section 7.

2.0 DESCRIPTION OF PM_{10} EPISODES IN THE WASATCH FRONT REGION

High concentrations of PM_{10} in the Wasatch Front Region can be attributed to a combination of meteorological conditions and emissions patterns. A typical pattern which produces high PM_{10} concentrations can be described by the following conceptual description (EPA, 1999). A high pressure system in the Wasatch Front region develops, producing a temperature inversion below the peaks of the surrounding mountains. During the winter, with enhanced surface albedo from snow covered ground and a low sun angle, the inversion is more likely to persist. These inversions are typically most shallow at night and will deepen during the day, dependent on solar heating. In the morning, motor vehicle emissions increase due to the morning rush hour and, since the inversion is shallow, PM_{10} concentrations rapidly increase. As the day progresses, the inversion layer will deepen, allowing PM_{10} concentrations to decrease. If it is a sunny day, with no ground level fog, the inversion will deepen dramatically and pollutant emissions may be ventilated out of the inversion layer. If it is cloudy or foggy, the inversion layer will persist, allowing high PM_{10} concentrations to build throughout the day, particularly secondary PM_{10} concentrations. Formation of secondary particulates is enhanced by high relative humidity. Therefore, in the presence of fog, the pollutants are trapped and conditions are conducive to secondary particulate formation. In the late afternoon, the evening rush hour emissions, in combination with the evening decrease in the depth of the inversion layer, will again cause PM_{10} concentrations to increase. This daily pattern is demonstrated in Figure 2-1. Figure 2-2 demonstrates the correlation between shallow inversion layers (low mixing height) and high particulate concentrations. Figure 2-2 also illustrates that PM_{10} consists primarily of secondary particulates (i.e., $PM_{2.5}$) in the Wasatch Front region. Consistent with the above description, the highest PM_{10} concentrations occur in stagnant conditions with low winds (Figure 2-3). This indicates that the particulate problem in the Wasatch Front region is not primarily due to wind blown dust.

2.1 Air Quality

Wintertime primary PM_{10} particulates are generally created during a burning process and include fly ash (from power plants), carbon black (from automobiles and diesel engines), and soot (from fireplaces and wood stoves). The PM_{10} particulates from these sources contain a large percentage of elemental and organic carbon which play a major role in haze phenomena and health effects. Secondary formation processes are also an important contributor toPM_{10} particulate mass in areas having inventories of the chemical precursors.

Elevated PM_{10} levels are generally associated with high-density urban areas or localized mountain valleys where industry, automobiles, wood burning, sanding and unpaved roads are common sources. Currently, Salt Lake and Utah counties and Ogden City are designated non-attainment for PM_{10}.

2.2 Meteorology

Most exceedances of the 24-hour average National Ambient Air Quality Standard (NAAQS) for PM_{10} measured along the Wasatch Front occur during extended periods of stagnation during the winter months. The key components of the meteorological conditions during such stagnation periods consist of: an intrusion of a cold air mass; snow cover; light and variable surface winds; surface based temperature inversion; fog or high humidity. Details of the preceding meteorological components of an episode of elevated PM_{10} are discussed in Section 2.3.

2.2.1 Air Mass Surface Temperature

A PM_{10} episode is normally associated with a cold frontal passage with an associated high-pressure system behind the front (surface pressures will build to near 30.40 inches, mercury).

2.2.2 Snow Cover

Snow cover is an element of the meteorological conditions that plays a dual role in the PM_{10} episodes. First, snow cover acts as a reflector of incoming solar radiation that inhibits heating near the surface, thus supporting the formation and maintenance of a surface inversion. Second, the snow cover acts as a source of moisture which helps produce the fog associated with the inversions. The existence of fog plays a role in the chemical reactions that produce secondary sulfate and nitrate.

2.2.3 Winds

The winds during a typical PM_{10} episode are usually light and variable (speeds less than 5 miles per hour), and are influenced by local topographic features. The mountain/valley regime provides diurnal upslope/downslope patterns; the lake/land interface presents onshore/offshore patterns which support and enhance the mountain/valley pattern.

2.2.4 Temperature Inversion

Typically during a PM_{10} episode a surface inversion (increasing temperature with height), which has a top lower than the surrounding mountains, persists for several days. Such inversions create a cap to the pollutants in the lower valley elevations. With respect to the model (UAM-AERO) an important parameter is the diffusion break height (DIFFBREAK) or mixing height (refer to section 5.3.5 for detailed discussion of the DIFFBREAK calculation). The pattern of mixing heights is that the lowest point is in the early morning hours. The top of the inversion during the early morning hours is usually only 100 - 200 feet above the valley floor. Above the inversion the air is clear and clean while areas below the inversion top and at the surface experience high PM_{10} concentrations.

The National Weather Service calculates a daily clearing index that indicates a relative potential for pollutant build-up. The clearing index is a non-dimensional number that combines the height of the inversion (mixing depth) with the wind speed within the mixing depth. When the clearing index is less than 500, dispersion is poor and represents a high potential for high pollutant concentrations. When the clearing index is below 100, severe stagnation conditions exist.

2.2.5 Fog

Snow cover acts as a source of moisture which helps produce the fog and high the relative humidity associated with the inversions. The existence of moisture plays a role in the chemical reactions that produce secondary sulfate and nitrate.

2.3 PM_{10} Episode Selection

The Utah Division of Air Quality (UDAQ) has not monitored an exceedance of the PM_{10} NAAQS in Salt Lake County, Utah County or Ogden City during winter-time inversion events in the past six years. PM10 data collected during the 6-year period suggests that at all sites (Utah and Salt Lake Counties and Ogden City) winter-time inversions occur simultaneously and produce the highest PM10 concentrations outside of "special events." Only special events, such as, the July holidays and spurious wind events produce higher PM10 concentrations. Furthermore, the top 2 non-flagged PM10 values recorded at Ogden City since 1993 are captured in the February 1-8, 2002 candidate modeling episode discussed below. Therefore, Salt Lake County, Utah County, and Ogden City will be evaluated using the same PM10 episodes.

Several "special event" PM10 NAAQS exceedences have occurred during the last 6 years. Several events have occurred during July 4th related firework activities near Ogden City while the other "special events" occurred during late winter and spring at Magna and the Kennecott Mine tailings pond. The tailings pond PM10 exceedences developed during dry high wind events. These conditions are very different than the stagnant inversion conditions that often plague the Wasatch Front with elevated PM10 levels.

The episode selection criteria for UAM-AERO modeling addresses only the primary meteorological conditions that produce elevated region-wide PM10 concentrations. No attempt will be made to model the wind blown fugitive dust events related to BACM failures at the Kennecott Mine tailings pond.

During this six-year period, three meteorologically significant inversions occurred without associated exceedances of the PM_{10} NAAQS. Consequently, UDAQ believes that Salt Lake County, Utah County and Ogden City are candidates for re-designation to attainment of the PM_{10} NAAQS. UDAQ plans to submit a Maintenance Plan supported by UAM-AERO photochemical modeling to demonstrate that Utah County, Salt Lake County and Ogden City do not currently exceed the PM_{10} standard and will not exceed it in the future during winter-time inversion events. The modeling effort relies upon recent, representative inversion episodes for the modeling baseline. This section discusses the episode selection process for the Maintenance Plan modeling.

2.3.1 Candidate Modeling Episodes

Modeling guidance ("Draft Guidance for Demonstrating Attainment of Air Quality Goals for PM2.5 and Regional Haze" EPA, Draft 2.1, January 2, 2001) recommends that modeling episodes are chosen from the three years following the implementation of the PM2.5 NAAQS. This recommendation is identical to the 8-Hr ozone modeling guidance. Because the emissions inventory is collected annually, by reviewing the past three-year period UDAQ will apply this standard to the choice of episodes for Maintenance Plan modeling. Monitoring and meteorological data during the most recent three-year period (1999-2002) indicates three inversion periods accompanied by elevated PM_{10}. The data available from the most recent three-year period are significantly more abundant than has been available prior to 1999. These data (both meteorological and monitoring) are crucial elements for the successful completion of a photochemical modeling effort.

During these recent inversion periods, the PM_{10} NAAQS was not exceeded in the Wasatch Front. Despite the lack of PM_{10} exceedances, UDAQ will show that these episodes are representative of typical inversions during which the PM_{10} NAAQS was exceeded in the past. The lack of PM_{10} exceedances during recent years during inversion conditions is an indication of reductions in emissions levels in the airshed. These three episodes will be discussed in the following sections and their relative merit will be presented in comparison to previous episodes in 1989 and 1996.

2.3.2 Episode Selection

This section presents the rationale underlying the recommended modeling episodes for the PM_{10} Maintenance Plan modeling.

- In identifying candidate modeling episodes, the following activities were carried out: define the range of issues that bear on the selection of aerosol modeling episodes (e.g., regulatory planning requirements, model refinement and model performance testing);

- assess the availability and adequacy of emissions, meteorological, and air quality data for developing model inputs and assessing model performance;

- identify specific days to be modeled within each candidate episode; and

- identify the best candidate episodes for use in this study.

General Considerations

In developing the preliminary recommendations on modeling episodes, the available database was examined in terms of the following screening attributes (some were considered explicitly, others implicitly):

PM Maxima – Primary candidates are days for which there are high measured PM_{10} concentrations and also high measured concentrations of other primary and secondary pollutants (i.e., associated pollutants). In the case of a Maintenance Plan, we do not expect to find days with 24-hour PM_{10} values greater than the federal PM_{10} standard (150 $\mu g/m^3$). Instead we look for days with 24-hour PM_{10} values which are significantly elevated relative to "normal" levels.

Presence of a Persistent Inversion – Elevated PM_{10} concentrations tend to occur in the Wasatch Front region when there is a persistent strong inversion over the region. Identification of these periods can assist in episode selection.

Data Availability and Completeness – Another criterion used in selecting modeling episodes from the set of available days is data completeness. An acceptable modeling day should have available, at a minimum, complete (or nearly complete) routine monitoring data for preparing model inputs and evaluating model performance.

Specific Considerations

In developing the modeling protocol, each episode was examined in greater detail, with recognition given to the screening analyses identified above. The following were also considered (to the extent supported by readily available information) in developing the final set of candidate days.

Synoptic and Mesoscale Overview – The synoptic and mesoscale meteorological conditions should be representative of those conditions that produce PM episodes.

PM_{10} Maxima of Regulatory Significance – The PM_{10} maxima during the episode should be of sufficient magnitude that the episode can serve as a "design day" for evaluating alternative control strategies. In the case of a Maintenance Plan, the "design day" will not exceed the standard but will be representative of recent high values in the airshed. These values will then be evaluated in terms of future growth to demonstrate continued attainment.

Representativeness of Design Monitor – The peak monitoring sites should include sites which are representative of regional PM levels as well as sites which may be dominated by individual localized sources.

Representativeness of Emissions Conditions – The episode should not occur during anomalous emissions conditions, e.g., holidays or special events. Furthermore, the episode should not occur during an economic downturn.

Coherence of Surface Wind Patterns – The surface winds should produce fairly stationary, consistent, and predictable flow patterns throughout the modeling domain.

Data Availability for Initial and Boundary Conditions – Adequate surface and aloft data should exist to specify PM and precursor pollutant concentrations at the beginning of the episode (initial conditions) and at the inflow boundaries of the modeling domain (boundary conditions).

Data Availability for PM Performance Evaluation – The number and coverage of PM monitors should be such that the temporal and spatial resolution of these data are adequate to support model performance evaluation.

Data Availability for Multi-Species Testing – The number and coverage of non-particulate precursor pollutant species should be such that the temporal and spatial resolution of these data are adequate to support a performance evaluation of modeled precursor and product species.

Data Availability for Meteorological Model Evaluation – The meteorological data base should be rich enough in spatial (both horizontal and vertical) and temporal detail to support performance evaluation of the meteorological model(s).

Data Completeness – The minimum acceptable set of meteorological and air quality parameters needed for use in preparation of model inputs, performance testing, and control strategy evaluation should be available.

Desired Prototypical Behavior – The episode should display the desired source-receptor relationships that are required to allow assessment of alternative emissions control strategies.

Prospects for Successful Modeling – There should be a reasonable chance of success in producing an acceptable model performance evaluation of the episode, i.e., assessing whether the model performs properly for the correct reasons.

Computational and Schedule Considerations – The modeling analysis should be able to be completed in an acceptable period of time and using available computer resources.

2.3.3 Discussion of Candidate Episodes

Three candidate episodes occurred in the Wasatch Front during the past three years (1999-2002). The dates and characteristics of each of these episodes are outlined below. All particulate values discussed below are 24-hour averages. See Table 1 for PM_{10} monitoring values at sites within Utah County, Salt Lake County and Ogden City for the three recent inversion periods (referred to as episodes 3, 4, and 5) and for two past inversions (1989 and 1996 – referred to as episodes 1 and 2).

- 1/1/2001 – 1/10/01: This was a lengthy and persistent inversion period characterized by intermittent periods of elevated PM_{10} (5 days > 99 $\mu g/m^3$) values. There was a period of venting in the middle of this time period when PM_{10} values fell off significantly. This inversion period includes both Christmas Day and New Year's Day. Geneva Steel was at normal steel production levels however they were not operating the sinter plant during this time.

- 12/23/2001 – 1/2/2002: This episode was characteristically similar to the 2000/2001 episode but shorter in duration and the particulate values are more elevated than in the previous episode. This episode appears to be quite "classic" in the sense that the inversion intensifies and particulate values gradually build until the inversion breaks and particulate values fall off. This inversion period includes both Christmas Day and New Year's Day. Geneva Steel's coke ovens and sinter plant were shut down during this time period and the rest of their operations were being phased out.
- 2/1/2002 – 2/8/2002: This episode had the most intense meteorology of the three episodes, i.e., the inversion was very shallow and persistent with little venting. At the end of this episode particulate values jumped dramatically (PM_{10} rose from 101 $\mu g/m^3$ on 2/5/2002 to 134 $\mu g/m^3$ on 2/7/2002). During the morning of February 8, 2002, the inversion broke with high winds and particulate values plummeted to 42 $\mu g/m^3$ for PM_{10}. This time period coincided with the days just prior to the start of the 2002 Winter Olympic Games held in Salt Lake City. As such, traffic numbers and patterns were somewhat different than usual. Geneva Steel was shut down during this time period.

2.3.4 Meteorological Discussion of Candidate Episodes

Although the episodes discussed above display relatively high values for PM_{10}, they are different meteorologically. The inversion strength cannot be quantified by direct measurements, but information about the variability of temperature and wind with height can give a good indication of inversion height and characteristics. A radiosonde (a balloon born instrument package that measures atmospheric parameters during the balloon's ascent) can provide this information.

Table 2-2 includes calculations based on data extracted from National Weather Service radiosondes launched from Salt Lake City, Utah (KSLC). The Salt Lake City radiosonde provides data on the vertical structure of the atmosphere two times daily. In Salt Lake City the balloons are launched in the early morning (00Z = 5 AM) and the late afternoon (12Z = 5 PM) local time.

The calculations in Table 2-2 are designed to characterize the strength of atmospheric inversions that occurred in Salt Lake and Utah valleys on the indicated multi-day episodes. Significant inversion episodes (episodes 1 and 2) from the winter of 1989 and 1996 are included for comparison. These meteorological parameters are discussed and defined in Appendix A. In terms of PM_{10} values, these 5 episodes include the most polluted days since the winter of 1989.

The three candidate episodes (3, 4, and 5) for the Salt Lake County PM_{10} Maintenance Plan occurred between 2000-2002. The inversion strength varied during these three episodes. The weakest of the 3 episodes was episode 3. The average depth of the inversion layer was highest and the strength of the inversion, as measured by the slope of potential temperature within the inversion, was weakest. Of the remaining 2 episodes, episode 4 had the lowest inversion depth but the slope of potential temperature was weaker than episode 5. Wind speed and relative humidity were comparable during episode 4 and episode 5 while temperatures were substantially colder during episode 5.

Table 2-1 offers corroborating evidence to the relative strength of the 3 inversion episodes in the most recent three-year period. The highest PM_{10} values were measured during episode 5. Data from the NWS radiosonde and PM measurements all indicate that episode 3 was weakest while episodes 4 and 5 were strongest.

Table 2 includes episodes in 1989 and 1996 as points of comparison. The data suggests that the 1989 and 1996 episodes were the strongest since the late 1980s. The PM_{10} values measured during 1989 have not been surpassed since then. Episodes ranked by highest measured PM_{10} are: 1, 2, 5, 3, 4. Episodes ranked by strongest inversion are: 2, 1, 4/5, 3. The difference in the ranking order for PM_{10} and inversion strength is indicative of changes in the emissions in the airshed over the past 15 years largely due to control strategies in the PM_{10} SIP

Table 2-1. PM_{10} Episode Monitoring Data

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Table 2-1. PM$_{10}$ Episode Monitoring Data

Table 2-1. PM10 Episode Monitoring Data from 1989, 1996, 2000, 2001, 2002									
Historical Episodes	Episode	Date	AMC	Lindon	Magna	N Provo	NSL	SLC	Ogden
	1	1/16/1989		139	49	94	82	84	62
		1/17/1989	129	158	81		127		
		1/18/1989	171	185	97		169	167	91
		1/19/1989	164	198	66		122		
		1/20/1989	159	260	65		103	165	44
		1/21/1989	133	213	49		64		
	Episode	Date	AMC	Lindon	Magna	N Provo	NSL	Cottnwd	Ogden
	2	2/13/1996	125	141					
		2/14/1996	151	147	88	120	157		98
		2/15/1996	149		103		162	130	96
Candidate Episodes	Episode	Date	Hawthorne	Lindon	Magna	N Provo	NSL	Cottonwd	Ogden
	3	12/26/2000	31	45	23	26	41	34	
		12/27/2000	59	58			69		
		12/28/2000	79	67			84		
		12/29/2000	92	65	51	59	91	88	
		12/30/2000	103	70			81		
		12/31/2000	93	66			90		
		1/1/2001	79	71	38	59	59	76	
		1/2/2001	65	77			62		
		1/3/2001	90	87	60		86		
		1/4/2001	101	89		nd	81	91	
		1/5/2001	105	86			85		
		1/6/2001	80	100			63		
		1/7/2001	68	87	42		60	63	
		1/8/2001	91	73		61	74		
		1/9/2001	100	72			98		
		1/10/2001	63	10	nd	nd	60	61	
	Episode	Date	Hawthorne	Lindon	Magna	N Provo	NSL	Cottonwd	Ogden
	4	12/23/2001	nd	44			42		30
		12/24/2001	52	65	31	nd	55	56	42
		12/25/2001	66	73			68		43
		12/26/2001	80	76			nd		53
		12/27/2001	101	111	61	93	nd	104	62
		12/28/2001	nd	101			97		87
		12/29/2001	103	82			89		81
		12/30/2001	82	98	nd	95	71	nd	85
		12/31/2001	91	60			41		75
		1/1/2002	54	54			97		86
		1/2/2002	43	38	20	41	50	38	34
	Episode	Date	Hawthorne	Lindon	Magna	N Provo	NSL	Cottonwd	Ogden
	5	2/1/2002	43	46	27	36	53	45	44
		2/2/2002	58	60			72		47
		2/3/2002	76	63			79		60
		2/4/2002	79	90	53	82	78	84	79
		2/5/2002	93	101			83		94
		2/6/2002	123	105			114		106
		2/7/2002	130	90	nd	79	121	119	134
		2/8/2002	25	17			42		40

Table 2-2. Meteorological Parameters Obtained from Soundings for Five Episodes

Episode	Date	Inversion Depth Avg Depth (m)	Inversion Depth 12Z Depth (m)	Inversion Depth 00Z Depth (m)	Potential Temp. Slope within Inversion Avg (C/km)	Potential Temp. Slope within Inversion 12Z (C/km)	Potential Temp. Slope within Inversion 00Z (C/km)	RH 12Z (%)	RH 00Z (%)	Wind 12Z (kts)	Wind 00Z (kts)	Temp 12Z C	Temp 00Z C
1	Jan 89	134.8	106.5	162.3	482.6	1009.2	583.4	86.0	80.0	5.5	5.3	-9.2	-4.1
2	Feb 96	108.8	42.5	174.5	1238.1	3305.0	404.5	98.3	61.6	3.3	6.0	-4.1	4.3
3	Dec 00/Jan 01	272.0	342.5	201.5	50.3	39.6	70.1	94.3	87.8	3.7	2.8	-6.9	-4.6
4	Dec 01/Jan 02	168.3	144.5	191.5	203.9	924.8	86.9	93.8	88.1	8.3	2.9	-4.0	-1.6
5	Feb 02	215.8	165.8	265.3	247.0	2060.8	24.3	90.5	78.0	2.8	8.0	-10.9	-4.4
Interpretation (implication for elevated PM10 potential):		Low depth implies elevated PM10 potential			High slope implies elevated PM10 potential			High RH implies elevated PM10 potential		Low winds implies elevated PM10 potential		Low temp. implies elevated PM10 potential	

2.3.5 Recommended Episodes

The episodes selected to represent the Wasatch Front in the PM_{10} Maintenance Plan are January 1, 2001 through January 10, 2001 (episode 3), and February 1-8, 2002 (episode 5). These episodes were chosen based upon the above discussion of the relative characteristics of the three candidate episodes. Episode 3 was chosen over episode 4 because Geneva Steel was operating during episode 3 (although at reduced capacity), but was in the process of shutting down during episode 4. Episode 4 is worse meteorologically than episode 3, but Geneva Steel's emissions are a crucial portion of the Utah County inventory. Episode 5 is the worst episode meteorologically in the last six years and is therefore crucial for demonstrating maintenance of the PM_{10} NAAQS in the future. The first of these episodes includes the Christmas and New Year's holidays. The second episode includes the days just prior to the Salt Lake City Winter Olympic Games. Both of these time periods will have some exceptional emissions but UDAQ will attempt to address these as appropriately as is possible. Extensive speciated data and meteorological data are available for both of these episodes.

Description of Meteorological Terms

Depth:
The radiosonde data are analyzed for the elevation at which the potential temperature gradient equals or exceeds $+2^{\circ}$ C / km. The height of this elevation above the surface is the inversion depth. The 12z, 00z, and the average inversion depth are indicated. Note that the depth is based on the first elevation at which the threshold is met. The inversion may continue through higher elevations.

Relevance:

The $+2^{\circ}$ C / km threshold indicates a "cap" or strong inversion in the atmosphere.

Thus, smaller depth values indicate a "tighter" inversion and increased potential for pollutant concentration buildup.

Slope:
The slope of potential temperature within the inversion layer. Slope is calculated by dividing the change in potential temperature within the inversion layer by the depth of the inversion layer. The number is multiplied by 1000 to produce units of degrees/kilometer. The 12z, 00z, and the average potential temperature slope are indicated.

Relevance:

The slope indicates the strength of the inversion layer. Increased slope indicates increased inversion strength.

Relative Humidity (RH):
The average relative humidity within the inversion layer.

Relevance:

High values of relative humidity may indicate the presence of fog and water droplets. Moisture can increase pollutant reaction rates leading to high pollutant values.

Wind:
The average wind speed (knots) within the inversion layer.

Relevance:

Wind can disperse pollutants. Stagnant air promotes pollutant buildup.

Temperature:
The average temperature (Celsius) within the inversion layer.

Relevance:

Cold temperatures can reduce reaction rates and decrease inversion mixing.

Definitions:
• 12Z - 05:00 am Mountain Standard Time.
• 00Z - 17:00 pm Mountain Standard Time.
• Potential Temperature – The temperature an air parcel would have if it were compressed adiabatically from its existing pressure (altitude) to a standard pressure (1000mb). Potential temperature is a normalized measure of temperature that allows temperatures at different altitudes to be compared.

2.4 Definition of Modeling Domain

The proposed modeling grid domain is shown in Figure 2-9. This domain was chosen to include the area within which winds might transport pollutants during the 2001 and 2002 episodes. This domain covers all or part of 13 counties and extends from the west edge of the Great Salt Lake to just east of the eastern edge of Utah County, and from Logan in the north to Manti in the south. This grid consists of a 33 x 56 array of 4 km grid cells. Table 2-3 gives the specific grid with its spatial resolution and UTM origins.

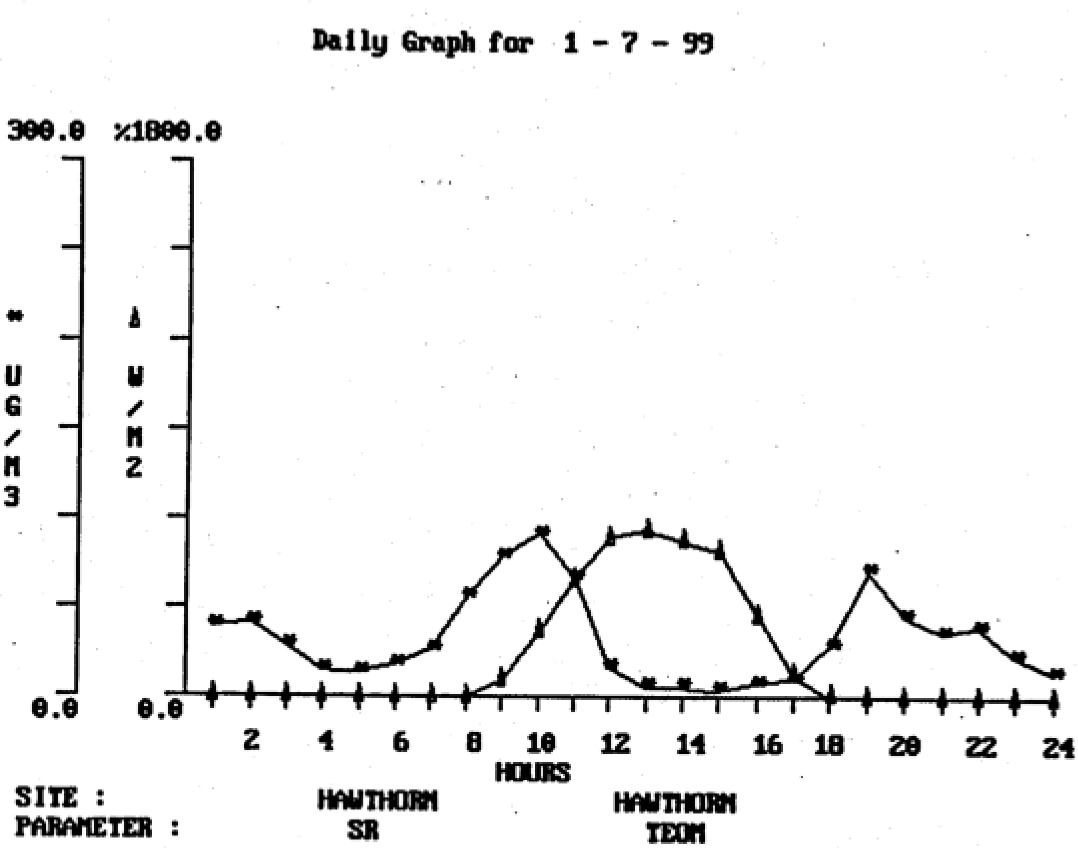


Figure 2-1. Daily Variability in PM_{10} (TEOM) Concentrations and Solar Radiation

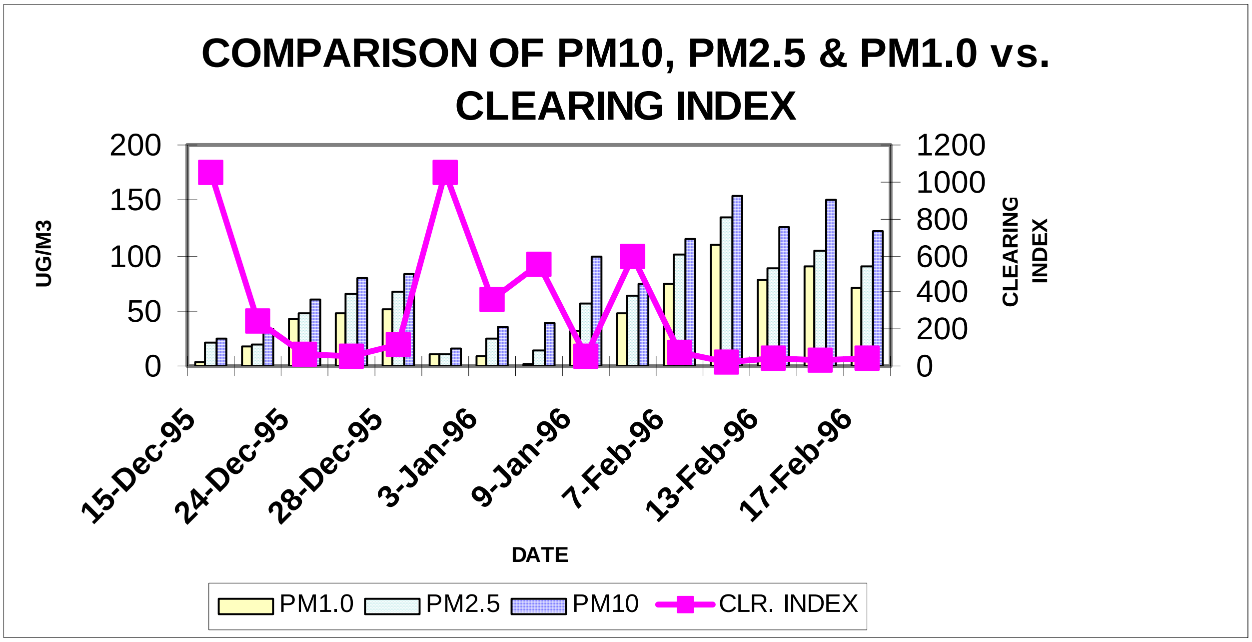


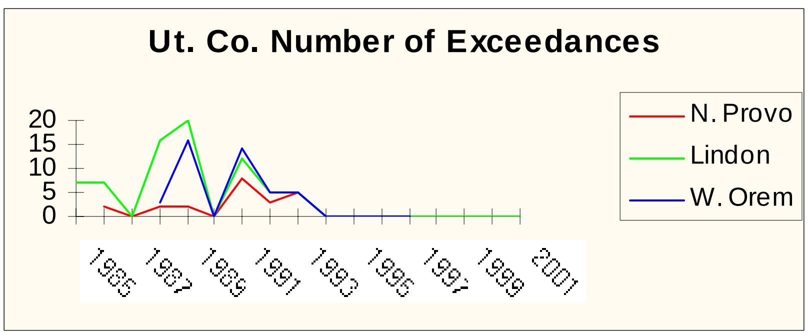
Figure 2-2. Comparison of Particulate Concentrations and Clearing Index

Clearing index is directly proportional to the mixing height. This figure illustrates that a small clearing index (low) mixing height and shallow inversion layer) corresponds with high PM concentrations. Notice that the fraction of PM_{10} which is smaller than 2.5 µm represents about 70% of the total PM_{10}. $PM_{2.5}$ generally represents secondary particulates, i.e., sulfates and nitrates.

Utah County PM_{10} Exceedances

Number of Exceedances (>150 ug/m3)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
N. Provo		2	0	2	2	0	8	3	5	0	0	0	0	0	0	0	0
Lindon	7	7	0	16	20	0	12	5	5	0	0	0	0	0	0	0	0
W. Orem				3	16	0	14	5	5	0	0	0	0				



Salt Lake County PM_{10} Exceedances

Number of Exceedances (>150 ug/m3)

	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
AMC					7	0	14	8	0	1	0	0	0	0	0	0	0
N. SL	1	3	0	6	3	0	14	3	1	0	0	2	0	0	0	0	0
SLC		0	0	3	3	0	5	3	0	0	0						

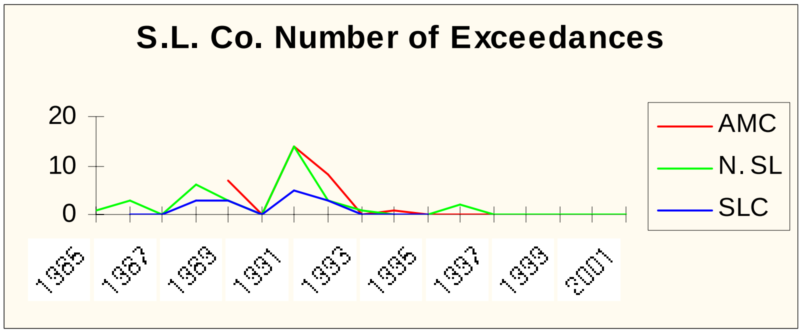


Figure 2-3. Number of PM_{10} Exceedances 1985-2001.

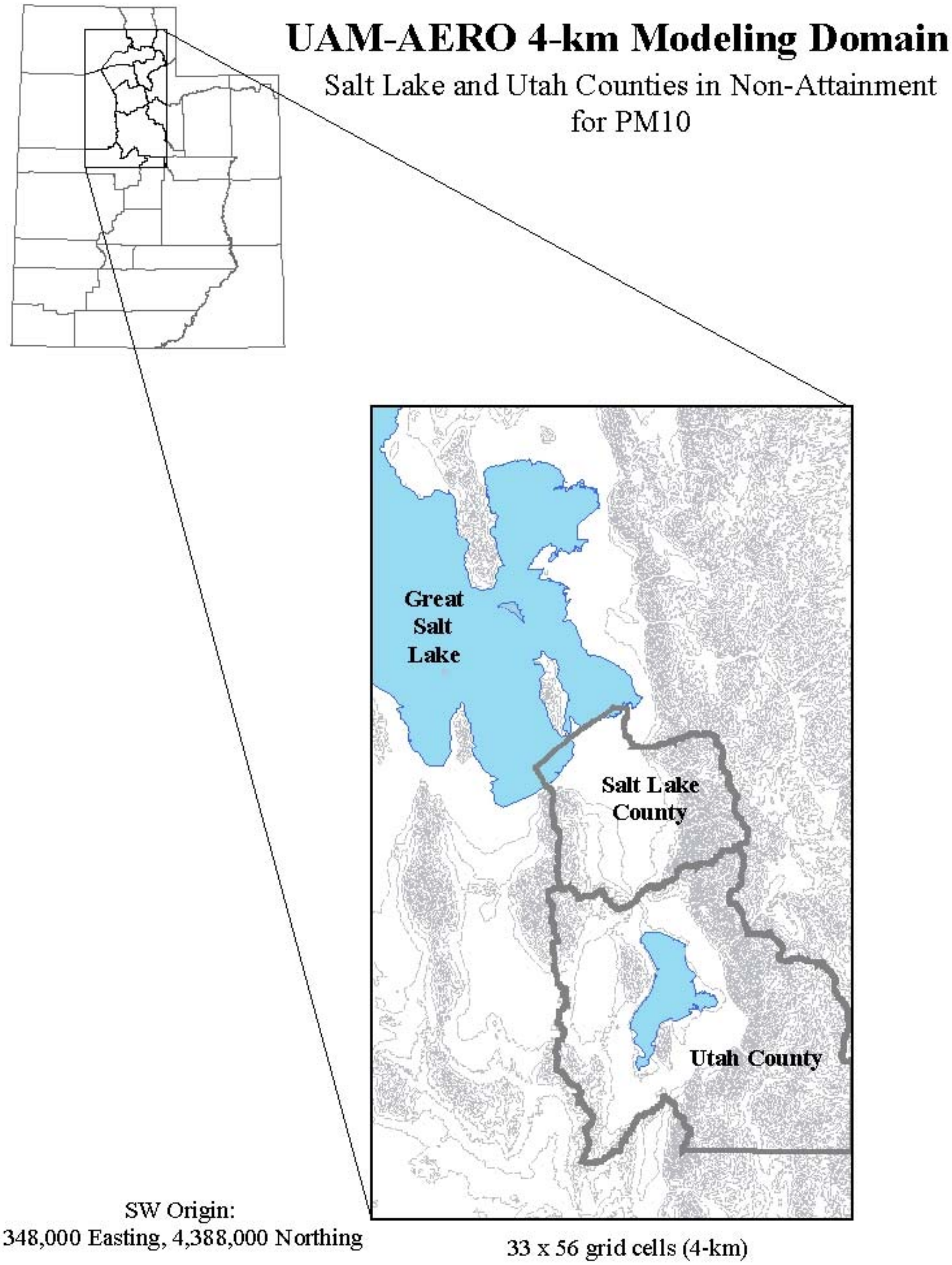


Figure 2-4. UAM-AERO Modeling Domain.

Table 2-3. Grid Definitions for the PM_{10} SIP modeling

(a) Horizontal Grid Definition

Model Code	Grid Cells East-West	Grid Cells North-South	UTM Origin East-West	UTM Origin North-South	Cell Size (km)
UAM-AERO	33	56	348 km	4388 km	4 km
SMOKE	67	113	348 km	4388 km	4 km

(b) Vertical Grid Definition

Model Code	Vertical Grid
UAM-AERO	5 layers - 2 below and 3 above the Diffusion Break

3.0 EMISSIONS MODELING METHODOLOGY

This section discusses the procedure for generating emissions inputs for the aerosol model.

3.1 Emissions Data Preparation

This section outlines the steps to be followed in developing emissions inputs to the UAM-AERO for each of the modeling episodes.

3.1.1 Delineation of Air Quality Planning Areas

The emissions modeling will cover the UAM-AERO modeling domain. This area includes Salt Lake, Utah and surrounding counties.

3.1.2 Emissions Preprocessor System

The U.S. EPA developed the Sparse Matrix Operator Kernel Emission (SMOKE) modeling system as part of the Models-3 Air Quality Modeling System. SMOKE is designed to create emissions inputs for photochemical or aerosol models from the basic point and area source emissions data typically compiled by state or local governmental agencies. SMOKE is a state of the art modeling system that will be used for developing UAM-AERO emissions inputs. The following discussion highlights the general features of SMOKE and presents the specific steps to be followed in exercising SMOKE with the emissions data sets for the study region. Figure 3-1a depicts the SMOKE system flow diagram for base case modeling; Figure 3-1b depicts the SMOKE system flow diagram for control strategy modeling.

3.1.3 Data Bases

The PM_{10} maintenance plan for the Wasatch Front will be based on 2 episodes that occurred in 2001 and 2002. DAQ plans to use the 2001 annual emission inventory for both 2001 and 2002 modeling episodes. Differences between the annual emissions inventory in 2001 and 2002 are minimal; therefore, the 2001 emissions inventory will be used for 2002. For each episode inventory, large sources located within the domain will be individually surveyed to determine if their operation was different from normal operations during any of the episode days. If so, changes will be made to the actual annual inventory emissions in order to replicate the way the sources operated during the episode days.

We propose to survey the point sources within the Wasatch Front with emissions of primary PM_{10} of 100 tons per year or more, NO_x of 200 tons per year or more, or SO_x of 250 tons per year or more to determine if any of them had unusual emissions or operating schedules during the PM_{10} episode periods. This information will be used to adjust the base year inventory to create the episode inventories. The episode inventories will use actual 2001 annual emissions by component for the majority of the sources. The annual emissions will be broken down to daily emissions by the profiles contained in the Sparse Matrix Operator Kernel Emission (SMOKE) model. Since all emissions must be entered into SMOKE using the same time period, the source daily episode data will be substituted for the annual emissions by multiplying the daily emission data by 365. The profiles in SMOKE will then break the emissions back down to the daily estimate.

3.1.4 Development of Future Year Emissions

The first step in evaluating future emissions control scenarios is the development of future year emissions inventories. Base year (i.e., 2001-2002) modeling emissions must be projected to some future baseline year (i.e., 2007, 2017, etc). The future year projected inventory(s) reflects the present state of affairs by reflecting the net effect of existing mandated controls and projected growth for each source category. The future year projected inventory(s) will include an assessment of the current banked emissions registry. The methodologies used to develop future year emissions projections should be consistent with EPA guidance. An Inventory Preparation Plan (IPP) has been developed separately to ensure that all inventories used in the modeling analysis, whether baseline or projection, are consistent with EPA guidelines. The IPP is included as supporting technical documentation to this analysis.

Upon completion of the projected emissions inventory, the aerosol model will be run to identify any areas in which projected growth and control would result in exceedances of the PM_{10} NAAQS. If so, sensitivity studies can be used to identify which source categories are likely to contribute to exceedances of the NAAQS. A control strategy committee would then incorporate this information into the development of emissions reductions strategies. These control strategies would be modeled to evaluate their effectiveness in meeting the PM_{10} NAAQS standard. Because of the complexity of PM_{10} source categories, specific control strategies would require detailed discussion and evaluation among the control strategy committee.

The emissions totals by source category must be compared with baseline emissions. Different plots can be used effectively to examine differences between the baseline and control strategy emissions inventories.

3.1.5 DAQ Emissions Data

The 2001 and 2002 base year emissions inventory for mobile, area and point sources for the UAM-AERO modeling domain will be compiled. The DAQ inventory will be reviewed at this stage in a preliminary quality assurance to ensure that complete data files have been captured and that no "suspect" point or area-wide sources are present. This review will help to confirm that the data are complete and representative of typical operating characteristics.

3.1.6 Land Use and Land Cover Data

Land use and land cover data are needed to perform several functions in developing a gridded emission inventory for use in the UAM-AERO. These data will be used to provide spatial allocation of county-wide emissions from area and mobile sources. County-wide emissions estimates will be disaggregated to individual grid cells in the modeling domain by using spatial allocation surrogates. Spatial surrogates will be developed from land use/land cover data and from demographic information. Typical surrogates include urban, suburban, rural, and agricultural land use as well as housing and population distributions. Spatial allocation factors are determined by calculating the fraction of a county's total for each surrogate in each grid cell. This fraction is then used to apportion county total emissions for each source category to individual cells.

Demographic and land use data will be acquired from the Utah Office of Planning and Budget and from the two metropolitan planning organizations (MPO's) for the Wasatch Front modeling region. Land cover data, railroad links and airports will be obtained from the USGS and digitized for allocating emissions from these categories. On-road motor vehicle traffic in the four-county Wasatch Front urbanized area will be allocated using the link location and volume data available from the MPO's MINUTP transportation modeling. Since on-road motor vehicles comprise a large fraction of the regions' emissions, they will receive considerable emphasis in the inventory preparation process.

3.2 Compilation of Emissions Estimates

3.2.1 General Emissions Inventory Information

The base year inventories will be assembled to ensure that emissions estimates are available for each grid cell in the full Wasatch Front modeling domain. The processing (e.g., spatial, temporal, and chemical gridding of emissions estimates) will be completed largely by using SMOKE. For example, SMOKE can take SIP inventory data and link-specific traffic volumes and produce gridded, speciated emission output files. SMOKE is designed to allow for adjusting emissions estimates to account for day-specific temperature effects; for time of day, day of week, month, and season, as well as projecting emissions into the future or backward to a historical episode accounting for emissions control effectiveness. Therefore, on-road motor vehicle emissions will be adjusted to account for episodic temperature effects. In addition, an attempt will be made to obtain day-specific activity information to adjust emissions from major point sources in the study domain. SMOKE provides national default parameters for temporally adjusting annual emissions and chemically speciating VOC emissions. Locale-specific data will be used preferentially over the national defaults where possible.

The UAM-AERO requires two emissions input files: (1) low-level sources, and (2) elevated point sources. Low-level emissions consist of low-level point sources, area sources, and mobile sources. The low-level area and mobile source emissions can be provided directly from the output of SMOKE. The SMOKE output file format is structured in three separate files covering point, area, and mobile sources. Additionally, the point sources are further divided into low-level and elevated point sources. Low-level point sources are those that have release points below the plume rise cut-off altitude and are eventually merged into the low-level sources for input to UAM-AERO. The remaining point sources, having discharge elevations greater than the plume rise cut-off point, are treated as elevated point sources. These latter sources are further processed with ELEVPOINT and

TMPPOINT to account for episodic meteorological conditions and to inject the emissions into the proper vertical layer of the UAM-AERO. All low-level emissions are then merged using SMKMERGE to create the low-level emissions input file for UAM-AERO.

3.2.2 Point Source Processing

Typical industrialized urban areas have thousands of point sources. Because it is impractical to treat every point source individually, some aggregation of point sources is necessary. Generally, sources emitting more than some threshold value or sources, regardless of size, exhibiting plume rise of approximately 25 meters or more are treated as point sources. Smaller sources are typically aggregated as area sources. The essence of point source emissions processing in SMOKE is converting inventory pollutant data for point source stacks from an aggregated annual, daily, or hourly emissions value to hourly and gridded emissions of the chemical species used by an air quality model.

The plumes arising from point source emissions extend high into the vertical structure of the air quality modeling grid definition. For these sorts of plumes, the plume rise needs to be modeled, and the emissions from these sources provided to the air quality model in three dimensions. An effective plume height for each point source to be treated is calculated based on an adaptation of the Briggs (1975) plume rise equations. These equations require as input stack height, diameter, temperature, and exit velocity as well as wind, ambient temperature, and Pasquill stability class.

The remaining point source processing steps are speciation, temporal allocation, projection, control, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each county, SCC code, plant ID, and stack ID is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles.

3.2.3 Area Source Processing

The procedure for gridding area source emissions estimates is well documented and straightforward. Generally, data are collected either by a state agency or by local air pollution control districts. Typically, the completeness and specificity of these databases vary considerably from one urban region to another, depending largely upon the level of effort given to quality assurance of the basic information. Based on work recently completed for a planning study in the Wasatch Front area, the available spatial surrogate data (e.g., population, housing, employment, agricultural, water, forest) are reasonably up-to-date, accurate, and complete.

The essence of area source emissions processing in SMOKE is converting inventory pollutant data for counties and source categories from an aggregated annual emissions value to hourly and gridded emissions of the chemical species used by an air quality model. The remaining area source processing steps are speciation, temporal allocation, projection, control, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each county and ASCT code is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles.

3.2.4 Mobile Source Processing

The essence of mobile source emissions processing in SMOKE is converting link and county (a.k.a., non-link) vehicle-miles traveled (VMT) data to hourly gridded emissions of the chemical species used by an air quality model. In order to do this, SMOKE creates, manages, and applies MOBILE6 emissions factors to the VMT based on a user-defined definition of a "mobile control strategy". This control strategy can define the motor vehicle parameters either for a specific year as it actually occurred, or for a hypothetical control strategy in the past, present, or future.

Emission factors are created in SMOKE using MOBILE6, for a wide variety of exhaust and evaporative processes and pollutants. Some of the MOBILE6 input parameters implement control strategies (e.g., inspection and maintenance (I/M) programs, anti-tampering programs (ATPs), and reformulated gas (RFG)). Other MOBILE6 inputs define other factors contributing to the value of the emissions factors, such as vehicle registrations (which help define the mix of different vehicle types), fuel volatility parameters, speeds, and temperature. All of these different dependencies cause mobile SMOKE to be more complicated than other SMOKE component models.

The remaining mobile source processing steps are speciation, temporal allocation, projection of VMT, and gridding. These are implemented using the standard emissions cross-reference and profile approach in which each combination of county, road class, and link is indirectly assigned a profile number by using a cross-reference file. A given profile number is used to find the appropriate temporal profile, speciation profile, etc., that transform the raw data using factors from the profiles. Typically, the highway network configuration and estimates of roadway traffic volumes are available with which to construct these link-based estimates. In areas where this information is missing or in short supply, it is possible to develop these inputs from total fuel sales, vehicle registrations, and similar information. Note, however, that a more detailed mobile source emissions modeling approach, utilizing output from the MINUTP transportation demand model, will be used in the urbanized portion of the study domain.

The MPOs and UDOT will be preparing VMT and speed data for the non-attainment counties as well as portions of other counties which fall within the modeling domain. Where feasible, results of transportation modeling of the study area will be used to support the development of on-road mobile source emissions estimates. If this information is not available, then county-level VMT data by vehicle class and roadway type will be used to estimate on-road emissions in the study area. The results of transportation modeling or these coarser VMT estimates will be used in conjunction with motor vehicle emissions factors from EPA's MOBILE6 model to provide the basis for estimating emissions from on-road motor vehicles. The MOBILE6 emissions factor modeling will incorporate locale-specific input parameters including hourly episodic temperatures. Estimates of vehicle miles traveled, vehicle hours of travel, and other relevant parameters will be obtained for the entire modeling region. The transportation modeling will also provide data necessary for spatial and temporal allocation of the on-road motor vehicle emissions data. On-road mobile source emissions for outlying portions of the domain will be spatially allocated using a combination of gridded population and/or land-use data and link locations.

Typically, the highway network configuration and estimates of roadway traffic volumes are available with which to construct these link-based estimates. In areas where this information is missing or in short supply, it is possible to develop these inputs from total fuel sales, vehicle registrations, and similar information.

Emissions factors for each type of on-road vehicle class (e.g., light duty auto, light duty truck, heavy duty truck) and various technology types (e.g., catalyst, non-catalyst, diesel) will be developed from "emissions factor models" such as the MOBILE6. The emissions factors used in conjunction with the link data mentioned above will address:

- Locale-specific inspection/maintenance (I/M) control programs, if any;
- Adjustments for running losses;
- Splitting of evaporative and exhaust emissions into separate source categories;
- Accounting for vehicle miles traveled (VMT) fleet fractions for light-duty gasoline vehicles and light-duty gasoline trucks;
- VMT growth, fleet turnover, and changes in fuel composition and Reid vapor pressure (RVP); and
- Factors to adjust base-year emissions from annual average to episodic conditions.

3.2.5 Biogenic Sources

Since the PM_{10} episodes occur during winter, biogenic emissions are assumed to be negligible and will not be modeled.

3.3 Temporal Adjustments and Speciation Profiles

3.3.1 Temporal Resolution of Emissions

To estimate hourly concentrations of particulates and precursor species, the UAM-AERO requires hour-by-hour estimates of emissions in each grid cell. There are several approaches for providing the temporal detail needed in the modeling inventory. The most accurate and exacting approach is to determine the emissions (or activity levels) for specific sources for each hour of a typical day in the time period being modeled. This approach, while applicable to certain of the major point sources in the Wasatch Front study area, is impractical for all sources.

The alternative approach to be followed involves reviewing available data and developing typical hourly patterns of activity for each source category and then applying these to the annual or seasonally-adjusted emissions to estimate hourly emissions. This approach, consistent with EPA guidelines, is commonly employed for area sources, and is usually used for all but the largest point sources. On-road motor vehicle emissions will be temporally allocated by using hourly traffic volume information, expected to be available for the major roads in the Wasatch Front study area. For most area and point source emissions categories, the EPA provides default temporal activity profiles. These defaults will be used in this study unless more relevant, site-specific data can be located, which allows more refined temporal allocation estimates.

Emissions are generally estimated for the day of the week on which polluting activities are at a maximum, normally a weekday. In some cases, simulating weekend conditions when automotive and industrial emissions levels are reduced or temporally shifted may be necessary. Here, additional temporal pattern information pertaining to weekend days must be used to construct a weekend modeling inventory.

3.3.2 Chemical Resolution of Emissions

Chemical speciation of emissions for UAM-AERO is described by the "User's Guide to the UAM-AERO Model" (Kumar and Lurmann 1996) and by Lurmann, et. al. 1997. In summary, the NO_x emissions are partitioned into NO, NO_2 and HONO. The NMOC emissions are partitioned into the appropriate classes for the CB-IV chemical mechanism. The PM_{10} emissions are partitioned into six chemical classes and approximately eight size bins below 10 µm and one or more size sections above 10 µm for fog droplets. The six PM_{10} chemical classes include sulfate, elemental carbon, organic carbon, crustal (or other PM species), sodium, and chloride. In addition, in the Wasatch Front region NH_3 emissions are an important consideration and will be identified individually rather than aggregated with the "other species".

3.4 Day-Specific Adjustments

Average winter day emissions will be used for area and low-level point source emissions. Unless episode day-specific activity and emissions data for major sources can be readily obtained, the temporal allocation will be based on the daily profile available for each source in AIRS AFS, and the emissions will be equal to the 2001 base year emissions.

3.5 Quality Assurance

A thorough review and quality assurance of the basic DAQ emissions data sets to be used in this study is well beyond the scope of this protocol. However, in the process of assembling and utilizing the DAQ emissions data sets, there are some activities that will be carried out to help identify the presence of potential problems or inconsistencies in the emissions sets. These activities are discussed below.

3.5.1 Assessment of EPA and DAQ Emissions Data Sets

Reasonable attempts will be made to assure that the 1999 DAQ and EPA Interim 2001 Emissions Inventory data are as complete and correct as possible. "Spot-checks" will be performed on the agency-supplied data sets to see if there are any major errors or consistency problems. During the reformatting process and the initial SMOKE executions, any missing parameters that would cause emissions to be dropped or misallocated will be investigated. Examples of errors that have occurred in similar databases in the past include:

- ASC/SCC codes missing from the SMOKE cross-reference tables, due to invalid or missing ASC/SCC codes; and

- Missing UTM coordinates for point source emissions.

To assure that the emissions are being properly handled by SMOKE, several emissions summary plots and tables will be produced and examined. The total emissions in the original input data sets will be calculated and compared with the emissions processed through SMOKE. The summary reports produced by each module of SMOKE will be examined and reconciled with the reports from other modules. In addition, plots of total daily emissions and selected hourly emissions will be produced for area source emissions, elevated point source emissions, low level (non-elevated) point source emissions, and motor vehicle emissions. These plots will be examined for spatial distribution and compared with area maps to confirm correct distribution.

3.5.2 Review of EPA Defaults and Data Sets

The default cross reference and lookup files provided by EPA for use with SMOKE for the Wasatch Front study area will be cross referenced. In particular, the following files will be reviewed and updated for conditions specific to the Wasatch Front area:

- Spatial surrogate files;

- Speciation profile files; and

- Temporal allocation files.

3.5.3 Preparation of Emissions Summary Reports and Plots

To aid in assessing the reasonableness of the UAM-AERO emissions inputs, daily total emissions by source category (e.g., area source, elevated point source, mobile source) will be tabulated for all major species (e.g., PM_{10}, NMOC, CO, NO_x, SO_2, and NH_3) for all modeling days. Quality assurance procedures that will be used to ensure the consistency and accuracy of the emissions inventories generated with the SMOKE model will include documentation of major assumptions, careful accounting of emissions totals throughout the development process, verification of spatial distributions of emissions against known locations, and identification of missing or unreasonable data values. The emissions files will be tabulated, plotted and examined before UAM-AERO simulations are performed. In support of this QA analysis, the array of graphical and statistical procedures in ARC-INFO and PAVE will be used to summarize and display the temporal and spatial allocation of emissions estimates by source category.

3.6 Emissions Forecasting

Forecasting (or projecting) emissions estimates to future years, accounting for the effects of growth and emissions controls, is a key element of emissions modeling. Emissions projections are creating using growth factors for area and mobile sources and for smaller point sources. Some significant point sources will use different methods of projection which will be discussed with EPA in the future. Control strategies will be developed and processed through SMOKE as needed

For stationary source emissions projection, changes are typically based on projected employment by industry type and population growth estimates. Generally, these data sets are obtained from governmental agencies. For cases in which these growth factors do not apply (i.e., for a small source category), projected population growth or no-growth assumptions may be used. For future-year activity levels, the anticipated effects of controls are implemented via a user-input file that defines the portion of emissions remaining after control is implemented.

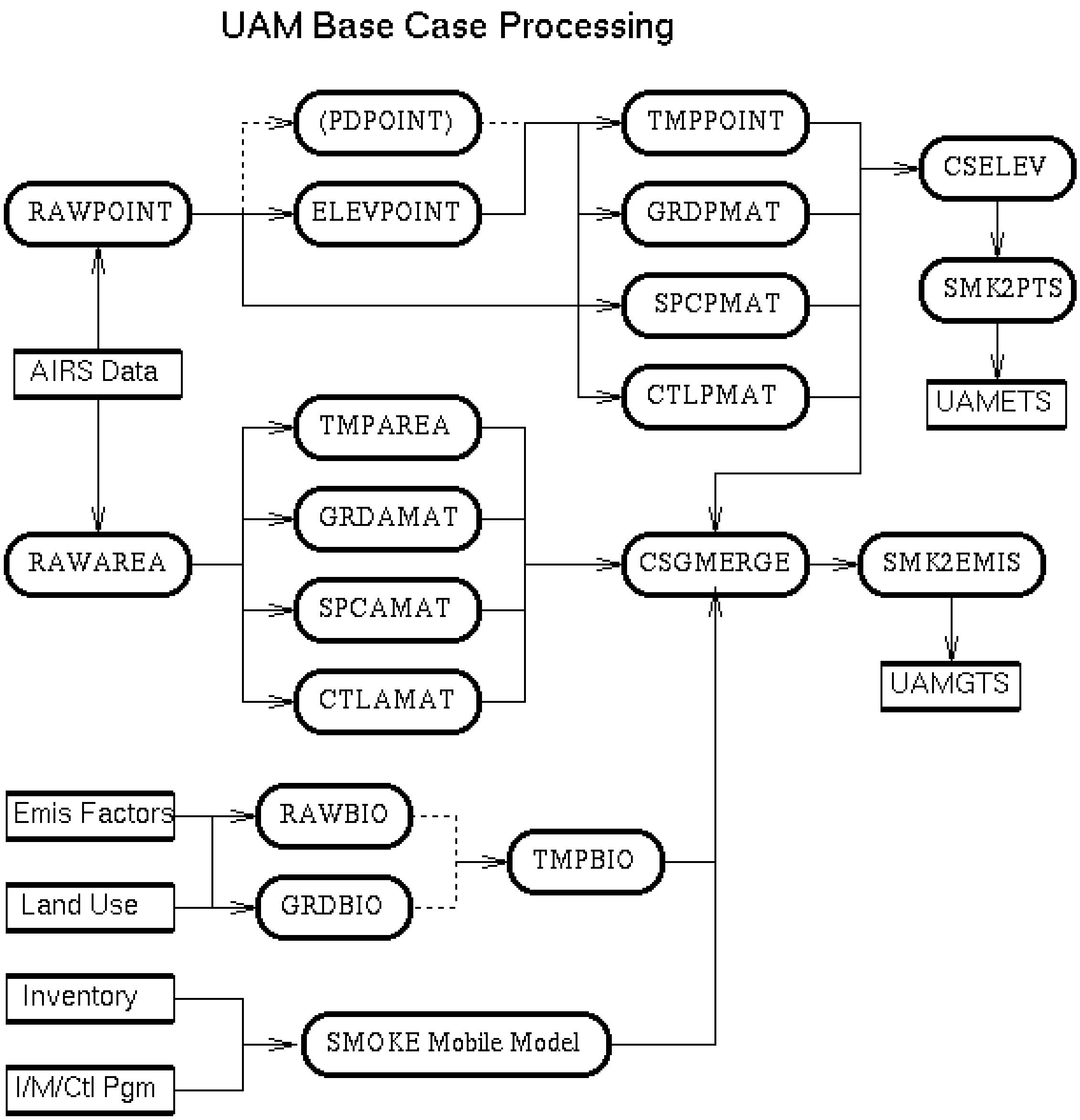


Figure 3-1a. SMOKE System Flow Diagram for Base Case Modeling

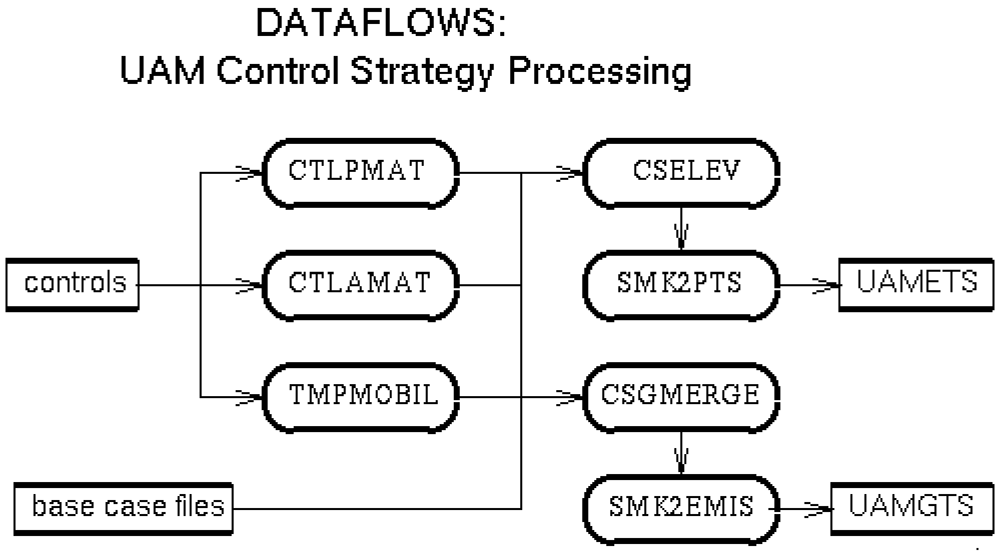


Figure 3-1b. SMOKE System Flow Diagram for Control Strategy Modeling

4.0 METEOROLOGICAL MODELING METHODOLOGY

The meteorological input preparation techniques for application of the UAM-AERO modeling system to the Wasatch Front, UT are described in this section. These inputs will be prepared in accordance with the general guidelines established by the U.S. EPA for the regulatory application of gridded photochemical models (EPA, 1991).

4.1 Meteorological Data Base

Surface meteorological data is available through the University of Utah Department of Meteorology Mesowest database. This database contains over 150 meteorological monitoring stations within the UAM modeling domain. The data will be used in the evaluation and development of the meteorological fields. Upper air data will be obtained from the University of Wyoming radiosonde database.

4.2 Meteorological Modeling

The availability of a high-density meteorological monitoring network will enable a diagnostic modeling approach. The diagnostic wind model (DWM) will be used to produce 3-D fields of wind speed and direction through 5 levels of the atmosphere. The UAM temperature preprocessor (INTERP3-D) will be used to produce 3-D temperature fields. Mixing height fields will be produced by the Atmospheric Boundary Layer Model (ABLM) using the wind and temperature fields as inputs.

The DWM modeling modeling system (DWMS) (wind, temperature, mixing height) will be executed over a 134 km x 226 km domain centered on Salt Lake City, UT (Figure 4-1). The horizontal modeling resolution will be conducted at 4km resulting in 7571 modeled grid cells. The vertical resolution will account for 5 layers at 200m, 400m, 800m, 1400m, and 2000m above ground level. The meteorological fields produced by DWMS will be used to create the meteorological input files to UAM-AERO. Figure 4-2 depicts the UAM-AERO modeling system.

Utah Air Monitoring Network

County	Station Name	Monitoring Parameters Measured										
		CO	NO2	NOx	O3	Pb	PM2.5 **	PM10 **	SO2	Temp	Wind Dir.	Wind Speed
Cache	Logan - L4	X			X		X	X		X	X	X
Box Elder	Brigham City - BR				X		X	X		X	X	X
	Promontory Point										X*	X*
Weber	Harrisville - HV				X		X	X		X	X	X
	Washington Blvd - W2	X										
	Ogden #2 - O2		X	X			X	X				
	Washington Terrace WT	X			X		X			X	X	X
Davis	Bountiful - BT	X	X		X		X	X	X	X	X	X
	Antelope Island										X*	X*
	Syracuse										X*	X*
Salt Lake	Hawthorne - HW	X	X		X		X	X		X	X	X
	Beach - B4				X				X	X	X	X
	Cottonwood - CW	X	X	X	X		X	X		X	X	X
	Herriman - HE				X					X	X	X
	Magna - MG					X		X	X	X	X	X
	North Salt Lake - N2						X	X	X			
	State St. - S3	X										
	West Valley - WV	X			X		X	X		X	X	X
	Salt Air										X*	X*
Utah	Highland - HG				X					X	X	X
	Lindon - LN						X	X		X	X	X
	North Provo - NP	X	X		X		X	X		X	X	X
	South Orem - SO	X										
	University Ave - U3	X										
	Spanish Fork - SF				X		X			X	X	X
Tooele	Grantsville - GV							X		X	X	X
	Badger Island										X*	X*

X* = Not real time data
PM10/PM2.5** = Speciated filter data availabile**

Table 4-1. Pollutants and Meteorology Measured at Air Monitoring Sites (April 2002)

Figure 4-1. DWMS modeling domain and Air Monitoring Site Locations (April 2002)

See Table 4-1 for site names and pollutants and meteorology measured at each site.

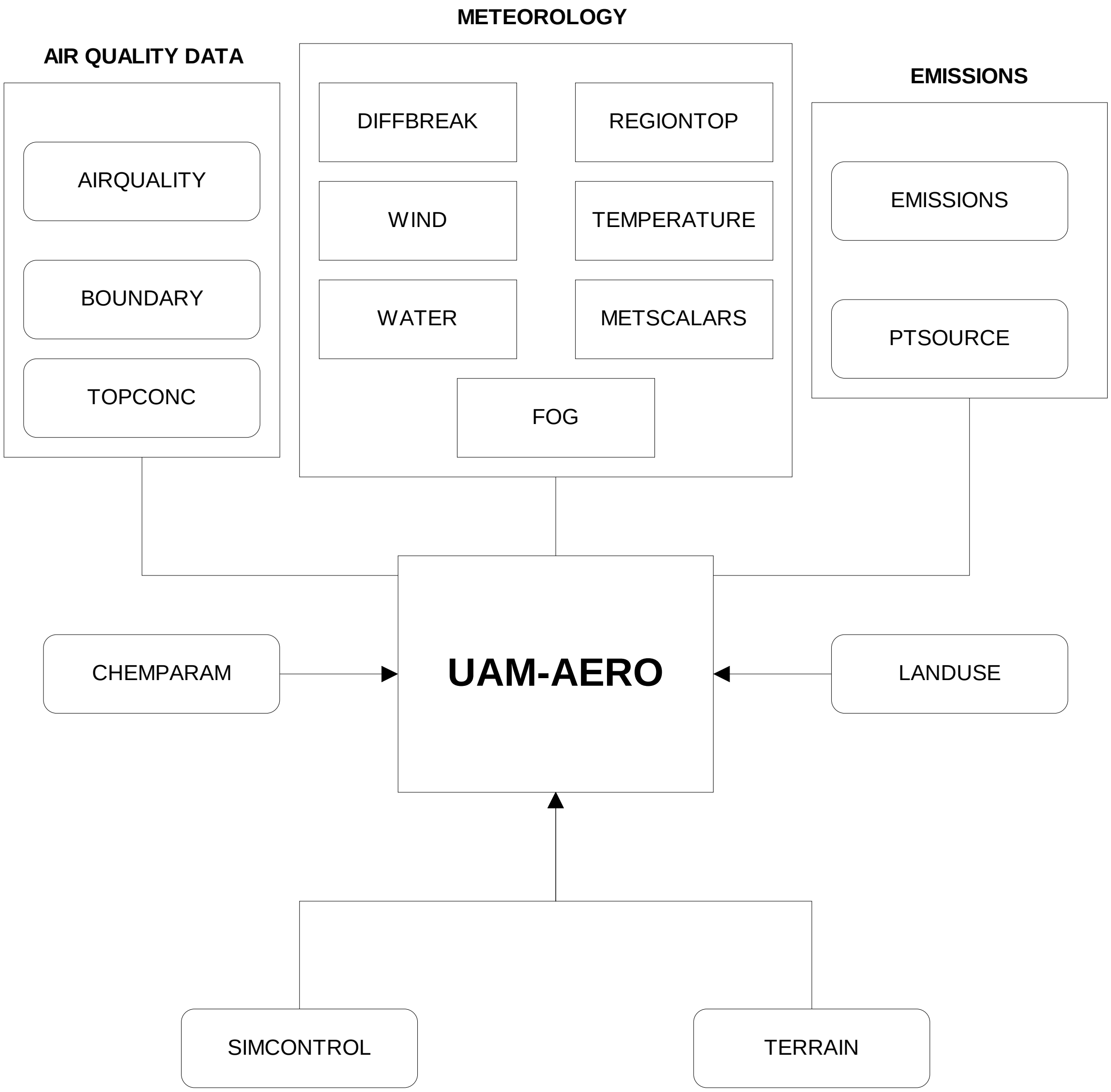


Figure 4-2. UAM-AERO Modeling System

5.0 AEROSOL MODELING METHODOLOGY

5.1 Air Quality Data Base

The bulk of the air quality data available for UAM-AERO application and evaluation will be obtained from the Utah Air Monitoring Center. Since 1996 the Air Monitoring Center's monitoring network has been enhanced. In addition, relevant data from other sources have greatly improved as well. Data have been obtained from various sources including the DAQ, the Aerometric Information Retrieval System (AIRS), the National Climatic Data Center (NCDC), the U.S. Geological Survey (USGS), the U.S. Forest Service (USFS), and several local and industrial sources. Land-use data for the preparation of gridded surrogates and the UAM-AERO land use file will be obtained from the USGS and the Utah Automated Geographic Reference Center (AGRC).

5.2 The Aerosol Dispersion Model (UAM-AERO)

The aerosol model to be used for the PM_{10} SIP modeling is the Urban Airshed Model with aerosol treatment employing CB-IV chemistry (UAM-AERO). The UAM-AERO is an Eulerian aerosol model that simulates the emission, transport, dispersion, chemical transformation, and removal of inert and chemically reactive species in the atmospheric boundary layer. The key feature of the UAM-AERO model is that it provides a common framework in which to evaluate relationships between ambient concentrations of both ozone and particulate matter (PM), and their precursor emissions. (Kumar and Lurmann, 1996; Lurmann, et al, 1997) Figure 4-2 presents the UAM-AERO system flow diagram.

5.2.1 Chemical Mechanism in UAM-AERO

The particulate mechanism in UAM-AERO is described in the "User's Guide to the UAM-AERO Model" (Kumar and Lurmann, 1996) and in Lurmann, et al, 1997. UAM-AERO simulates the effects of emissions injection, horizontal and vertical transport and dispersion, dry deposition, and chemical reactions on atmospheric concentrations of gaseous and particulate pollutants. The model quantifies the relationships between ambient PM concentrations and emissions of particles and of gaseous compounds that form secondary PM and/or affect the rate of secondary PM formation.

The emissions inputs to the model include six chemical components of particulates (elemental carbon, organic material, sulfate, sodium, chloride, and crustal material), and gaseous emissions of NO_x, SO_2, NH_3, VOC, and CO. The model predicts the following chemical components of PM as output: nitrate, sulfate, ammonium, sodium, chloride, elemental carbon, organic material, crustal material, and water.

UAM-AERO simulates the aerosol-size distribution as well as the chemical composition of the aerosols. Tracking aerosol size is important because the fate of particles in the atmosphere depends largely on their size. Particles grow and shrink in response to a number of physical processes and simulation of these dynamic processes is necessary to accurately predict the PM mass concentrations.

UAM-AERO also has a mechanism to simulate the effect of the presence of fog on gas and aerosol species. When haze or fog exist, the model allows particles to grow to sizes larger than 10 µm. Particle growth and shrinkage are determined by the amount of water transferred to and from the aerosol based on the equilibrium concentrations estimated by SEQUILIB for specific relative humidity, temperature, and aerosol chemical composition. Deposition of fog droplets is calculated using the same procedures used for other particles. In addition, aqueous-phase chemical reactions are simulated using the gas-phase chemistry operator.

5.3 UAM-AERO Input Preparation Procedures

The overall modeling system consists of a number of distinct preprocessing routines that produce files for input into the UAM-AERO main system. Figure 4-2 shows the UAM-AERO system in relation to each of the component preprocessors. Each of the input components is discussed in this section.

5.3.1 UAM-AERO Region Definition

The proposed UAM-AERO modeling domain (Figure 2-9) consists of a 33 x 56 grid (east-west by north-south) with a 4 km resolution. This region contains the bulk of the emissions in the greater Ogden-Salt Lake City-Provo region.

In the vertical, the following grid structure is proposed but will be finalized pending further review of the meteorological conditions during the modeled episodes.

•Five (5) vertical layers, two below the inversion and three above;

•A region top sufficiently high to contain all elevated point sources and the maximum inversion rise;

•A minimum cell height of 40 meters for layers 1 and 2 (below the inversion base); and

•A minimum cell height of 200 meters for layers 3 through 5 (above the inversion base).

5.3.2 AIRQUAL

The initial concentration fields for each episode will utilize air quality data collected within the Wasatch Front modeling domain. A distance-weighted interpolation will be used to generate gridded initial concentration fields. For concentrations aloft, an assumed vertical profile will be used to distribute the surface concentration estimates to UAM-AERO levels 2 through 5.

5.3.3 BOUNDARY

For inflow boundaries, hourly boundary conditions will be specified on the basis of observed air quality data at monitors. Where data are lacking, estimates of inflow boundary conditions will be based on upwind emissions source region considerations. Along those boundaries through which pollutant transport is not a factor, clean boundary conditions representing background concentrations of the pollutants (EPA, 1991) will be used.

5.3.4 CHEMPARAM

The species, rate constants, and other parameters contained in this file will be based on the requirements of the UAM-AERO CB-IV chemical mechanism and EPA default values.

5.3.5 DIFFBREAK

A number of techniques are available for estimating the mixing heights for UAM-AERO applications. Due to the complexity of the study domain, particularly the close proximity of mountainous terrain and two large lakes, the Atmospheric Boundary Layer Model (ABLM) will be used. ABLM uses the following inputs to develop the gridded mixing heights for UAM-AERO.

- Surface temperature
- Surface wind
- Surface pressure
- Cloud cover
- Inversion base height
- Inversion intensity
- Mean mix layer potential temperature
- Surface roughness length

5.3.6 METSCALARS

Meteorological data collected at the SLCIA and from the 2001 study sites will be used to estimate the spatially constant, temporally varying METSCALARS. These data include hourly values of atmospheric pressure and the exposure class (stability class). Because UAM-AERO has three-dimensional temperature and humidity fields, these values in the METSCALARS input file are dummy variables.

5.3.7 REGIONTOP

For each UAM-AERO modeling episode, the height of the top of the modeling region will be held constant throughout the simulation. This value will be based on the maximum mixing height for the modeling episode, as determined from the ADAS analysis.

5.3.8 SIMCONTROL

The starting time for all UAM-AERO simulations will be 0000 MST and will run though 2400 MST on the last day. All other information contained in the SIMCONTROL file will remain constant from one simulation to another.

5.3.9 TEMPERATURE

Gridded temperature fields for the UAM-AERO application to the Wasatch Front Study area will be derived from the INTERP3D interpolation module that is a part of UAM-AERO. This module is an enhanced version of the TEMPERATUR preprocessor in UAM-IV. The TEMPERATUR module generated a surface temperature field, INTERP3D generates a three dimensional temperature field.

5.3.10 TERRAIN

Gridded land use data for the modeling region will be derived by combining 1:250,000 scale USGS data with a much finer resolution, 30 meter land use data set created by they Utah AGRC. The surface roughness and deposition velocities as a function of land use will be derived from studies performed by the Argonne National Laboratory, as summarized in the UAM-IV users manuals. The land use values proposed for the Wasatch Front are listed in Table 5-1.

5.3.11 TOPCONC

Because no aloft air quality measurements are available to formulate day-specific concentrations for the top of the modeling region, the TOPCONC pollutant concentrations will be specified after reviewing all available information on air quality aloft from applicable field studies.

5.3.12 WIND

Wind fields for the Wasatch Front region will be generated using the DWM processor. Surface wind parameters will be used from the MESO-WEST meteorological network that includes has many met sites that can be added to the UDAQ air monitoring network. The processor, UAMWND, will then use the DWM and ABLM output to create the final model-ready met files.

5.3.13 WATER VAPOR

Gridded water vapor fields for the UAM-AERO application to the Wasatch Front area are derived from the relative humidity values used in INTERP2D. The processing of the water vapor fields is combined with the TEMPERATUR file preparation and is described in section 5.3.9.

5.3.14 FOG

An hourly, gridded two-dimensional fog field will be determined using relative humidity measurements as a surrogate. The fog field will be developed with the DWMS interp2d module using the following assumptions that are based on empirical evidence:
1) Fog - when RH > 90%
2) Haze - when 90% < RH > 60%
3) Clear - when RH < 60%

The fog file will be assigned values for clear, hazy, or foggy conditions for every hour in each horizontal grid cell in the first two vertical layers of the modeling domain.

5.4 Quality Assurance of Model Inputs

The meteorological, air quality, and land-use inputs will be plotted and examined to ensure: (a) accurate representation of the observed data in the UAM-ready fields, and (b) temporal and spatial consistency and reasonableness. This evaluation will include analysis of surface meteorological parameters (wind speed, wind direction, and temperature) as well as meteorological parameters aloft at the upper air sounding sites.

Table 5-1. Land Use Categories

Category	Land Use
1	**Urban land**
2	**Agricultural land**
3	**Range land**
4	**Deciduous forest**
5	**Coniferous forest**
6	**Mixed forest including wetland**
7	**Water, both salt and fresh**
8	**Barren land, mostly desert**
9	**Nonforested wetland**
10	**Mixed agricultural and rangeland**
11	**Rocky open areas with low-growing shrubs**

6.0 MODEL PERFORMANCE EVALUATION

6.1 Introduction

Because aerosol modeling is still in its infancy relative to photochemical ozone modeling, official guidance on model performance evaluation (MPE) is not available. The EPA has developed a guidance document for ozone model performance evaluation (U.S. EPA, 1991) that suggests specific tests and comparisons, recommends graphical methods for use in interpreting and displaying results, and identifies potential issues or problems that may arise. Another document titled "Improvement of Procedures for Evaluating Photochemical Models," (Tesche et al., 1990) provides a comprehensive discussion of MPE procedures and issues, and significantly influenced the EPA guidance document. More up-to-date guidance on ozone modeling (U.S. EPA, 1999a) is also available from EPA in draft form and includes suggestions on performance evaluation. While these documents focus on model performance for ozone, the basic MPE concepts are applicable to aerosol models. An EPA concept paper (U.S. EPA, 1999b) also provides some insight, albeit for modeling the fine fraction, on evaluating model performance.

Photochemical model performance evaluation is a process in which statistics play a crucial role, but are often not sufficient to tell the whole story. The evaluation process consists of:

- developing a plan or protocol for assessing the extent to which the modeling system emulates the real atmosphere;
- carrying out the appropriate simulations;
- comparing model estimates with observations;
- attempting to ensure that potential compensating internal errors do not exist or are minimized;
- identifying causes of model and/or database inadequacies;
- correcting the inadequacies where possible; and
- re-evaluating model performance.

The objective of this MPE is to determine if the UAM-AERO simulations performed for this study can be used to demonstrate maintenance of the National Ambient Air Quality Standards (NAAQS) for PM_{10}. In performing the evaluation we will try to answer the following questions:

- How close does the model simulate observed concentrations?
- What biases are exhibited by the model? What are the causes?
- What are the model's sensitivities and can they be quantified?
- Does the model respond, in direction and magnitude, to emissions changes in such a way that enables decision-makers to confidently use the model for policy development?

It should be noted that a prerequisite for model performance evaluation is thorough analysis of the air quality data to be used in the analysis in order to characterize the features of the data that need to be reproduced in the models. These analyses include not only the routine summary statistics and distributions for each station, but also comparisons of the spatial and temporal characteristics at different sites.

With photochemical models such as the UAM-AERO, the atmospheric diffusion equation is numerically integrated over time and the model estimates for a specific hour and location are not independent of the model predictions for other hours and locations. The lack of independence occurs because the models' calculations depend on the previous hour's concentrations. Thus, there is a need to examine the model performance (bias and error) for all hours of the day, as well as for the hours and locations where the highest concentrations were observed. If a model performs poorly for an hour before or an hour after a peak hour (but not at the peak hour), the simulation may be considered flawed because it did not simulate the processes leading up to and following the maximum concentration well. Other concerns are that photochemical model applications derive their credibility from not only the model performance statistics for the key product species (e.g., ozone, sulfate, or nitrate), but also the accuracy of the (1) predicted spatial, diurnal, and temporal (day-to-day) patterns of concentrations and (2) precursor species concentrations. Often, the results from each day of a photochemical model simulation are considered as independent predictions, even though technically this is not correct.

In this chapter we discuss methods for performing model performance evaluations and issues unique to evaluating aerosol model performance for the PM_{10} study. We describe the specific set of MPE procedures that will be applied to the UAM-AERO simulations performed for this study. We will also propose how the model results may be used, depending on the results of the MPE.

6.2 Model Performance Criteria for this Study

There are no universal acceptance criteria in photochemical modeling. Multiple statistics are used together with graphical displays to evaluate photochemical models because no one measure is adequate for characterization of performance. An attractive approach for determining "acceptance" of a model is for it to be derived from a lack of rejection in a series of planned tests. Tentative acceptance can be the result of many "nonrejections" in a prescribed evaluation process where both statistical comparisons with observed concentrations and graphical evaluation of predicted and observed patterns are considered. Acceptance is tentative because we can never have full information; rather, evidence builds to the point where we become comfortable with the prospect of a model being judged adequate in light of available information. Where possible, rejection criteria should be specified for all phases of testing.

A common problem in urban and regional modeling is that the model generates spatial patterns of pollutants that may be similar to the observed patterns. However, they may be shifted in time and/or space (elongated or broadened). Pattern recognition may be useful for analysis of spatial and temporal patterns. The classical statistical approaches to MPE do not provide sufficient information on the similarity of the spatial patterns, which could be useful in assessing performance. Because pattern recognition software has not been sufficiently tested for use with air quality data and there is little observational data available, we will rely upon subjective pattern recognition in this MPE. Emphasis will be placed on graphical analyses and evaluations will rely upon the modeling team's scientific understanding of the processes responsible for aerosol formation in the study region.

Multi-pollutant evaluations are particularly important for evaluating the performance of photochemical PM models. The same statistical measures of performance are generally used for all species, however, the criteria for rejection as well as the importance of certain measures may differ. Table 6-1 lists species that should be considered in evaluating aerosol models. Because of data limitations, the species, which will be evaluated in this project, are those discussed in Table 6-3. Comparisons should be made for the major precursors and products. Clearly, reactive models that simulate precursor and product species well are much less likely to be flawed than models that only simulate a single product species well. Often, the observational databases lack sufficient species to carry out multi-pollutant evaluations, which is likely to be the case in this study.

Table 6-1. Candidate chemical constituents for aerosol model performance evaluation.

Particulate Matter	Other Constituents
$PM_{2.5}$ Mass	SO_2
PM_{10} Mass	NH_3
$PM_{2.5}$ SO_4	O_3
PM_{10} SO_4	NO
$PM_{2.5}$ NO_3	NO_2
PM_{10} NO_3	NO_y
$PM_{2.5}$ NH_4	VOCs
PM_{10} NH_4	PAN
$PM_{2.5}$ OC	HNO_3
PM_{10} OC	
$PM_{2.5}$ EC	
PM_{10} EC	

For evaluating performance of an aerosol model, such as UAM-AERO, chemical composition and size distribution of the aerosols should be considered. Evaluation of aerosol mass alone is not sufficient. Chemical- and size-resolved observations for the episode being modeled should be considered in the analysis.

Photochemical aerosol modeling is more uncertain than photochemical ozone modeling for many reasons, which include:

- There are greater uncertainties in emission inventories for particulate matter
- Less is known about the physical and chemical processes contributing to aerosol formation and growth
- Observations of aerosols are more uncertain than observations of ozone

- Fewer observations are available to understand the spatial, chemical, and size distribution of aerosols in the ambient atmosphere and to use in model performance evaluation

This last point is particularly important. If we had only one observation of 24-hour average PM_{10} mass and could get perfect statistical performance at that location, there would still be a high level of uncertainty in the model's ability to correctly predict the response of PM_{10} formation to changes in the emission inventory. Only by making sure the model performs well for many locations and many predicted variables do we reduce uncertainty and gain confidence in the model's predictive ability.

Much of our community's experience in model performance evaluation has been with ozone. Historically, we have used photochemical ozone models to demonstrate attainment of the ozone NAAQS in an absolute sense. An absolute attainment demonstration is an approach that relies on verification that the model is performing within statistical limits determined by EPA. If the model performs to these standards, then the absolute values obtained from the base case and future year scenarios are used to evaluate whether a future year control strategy is sufficient for an area to attain the NAAQS. Typically, extensive field study data are used in model-input preparation and MPE for an absolute attainment demonstration. Unfortunately, we do not have extensive meteorological or air quality data to support an absolute attainment demonstration for the Wasatch Front PM_{10} aerosol modeling application.

Aerosol modeling is currently more uncertain than ozone modeling. Thus, we are unlikely to reach a level of confidence with aerosol modeling that will allow us to use it in an absolute sense. However, there may be cases where an aerosol model significantly under- or over-predicts particulate matter concentrations but the results of the MPE convince us that it is capable of predicting the correct response to emission changes. In that case it may be possible to use the model predictions in a relative sense. Relative reduction factors similar to those proposed in EPA's draft guidance on ozone modeling (U.S. EPA, 1999a) could be generated for the particulate matter components.

Because of the uncertainties associated with aerosol modeling, we propose two levels of testing and use for UAM-AERO. At the highest level, we propose tests and criteria that are comparable to those applied to ozone modeling applications. If the model performs well at this level, it would be reasonable to use the model in an absolute attainment demonstration. The rejection criteria at this level are summarized in Table 6-2. The following section on model performance evaluation methods and issues provides a detailed discussion of the statistical measures, graphical procedures, and sensitivity analyses that are summarized here.

Table 6-2. Rejection criteria for UAM-AERO use in an absolute attainment demonstration.

Tests	Rejection Criteria
Statistical	Statistics for 1-hr and 24-hr averaged $PM_{2.5}$ and PM_{10} (mass and chemical components), ozone, NO, NO_2, SO_2, NH_3, HNO_3, and VOCs are worse than EPA's ozone model performance criteria: • Normalized Mean Bias greater than +/- 15 percent • Normalized Mean Error greater than 35 percent • Unpaired Peak Prediction Accuracy greater than 20 percent Where bias and error are calculated for cases when the observed concentrations are greater than or equal to 10 percent of the maximum observed concentration during the modeled episode for each species.
Graphical	Modeled and observed species for the episode are not chemically, spatially, and/or temporally consistent.
Sensitivity	Responses for important secondary species inconsistent with our understanding of the processes leading to their formation.
Data	Type and/or quantity insufficient to perform statistical and graphical tests for all species indicated.

Based on the preliminary review of data available for evaluating the candidate episodes, we expect that, based on the data test, it will be difficult to use UAM-AERO in an absolute attainment demonstration. There may be insufficient data to carry out the detailed statistical and graphical evaluations proposed. The alternative is to use UAM-AERO to calculate relative reduction factors for use in the attainment demonstration. This approach is discussed in detail in the Attainment Demonstration chapter. **Table 6-3** provides a summary of observations expected to be available for the evaluation of the candidate episodes.

Table 6-3. Observations available for the model performance evaluation.

Constituent	Description	Sites	UAM-AERO Name	Units
$PM_{2.5}$ Mass	Particulate Matter < 2.5 μm	BR, BT, CW, HV, HW, LN, N2, NP, O2, SF, WT, WV	N/A	$\mu g/m^3$
PM_{10} Mass	Particulate Matter < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	PM10	$\mu g/m^3$
PM_{10} SO_4	Sulfate < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	SO4_1	$\mu g/m^3$
PM_{10} NO_3	Nitrate < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	NO3_1	$\mu g/m^3$
PM_{10} NH_4	Ammonium < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	NH4_1	$\mu g/m^3$
PM_{10} OC	Organic Matter < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	OC_1	$\mu g/m^3$
PM_{10} EC	Elemental Carbon < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	EC_1	$\mu g/m^3$
PM_{10} CL	Chloride < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	CL_1	$\mu g/m^3$
PM_{10} NA	Sodium < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	NA_1	$\mu g/m^3$
Other PM_{10}	Other particulate matter < 10 μm	BR, BT, CW, GV, HV, HW, O2, LN, MG, N2, NP, WV	OTR_1	$\mu g/m^3$
NO	Hourly Nitrogen Oxide	CW, O2	NO	ppm
NO_2	Hourly Nitrogen Dioxide	BT, CW, HW, NP, OG	NO2	ppm
SO_2	Hourly Sulfur Dioxide	B4, BT, MG, N2	SO2	ppm
CO	Hourly Carbon Monoxide	BT, CW, HW, NP, S3, SO, U3, W2, WT, WV	CO	ppm

With data availability in mind, we are proposing performance criteria for the relative use of UAM-AERO. The criteria are less stringent than those for use in an absolute attainment demonstration. However, they require that the tests provide consistent evidence that the model is capable of correctly predicting the response of PM_{10} concentrations to changes in the emission inventory.

Because of data limitations, the evaluation at this level will be more subjective and rely heavily on the modeling team's scientific understanding of aerosol formation and the model's ability to replicate important processes in this formation. **Table 6-4** summarizes the criteria that we will use to reject or accept the use of UAM-AERO for calculating relative reduction factors to use in the attainment demonstration.

Table 6-4. Rejection criteria for UAM-AERO in a relative attainment demonstration.

Tests	Rejection Criteria
Statistical	Statistics for 24-hr average chemical components of PM_{10}: • Normalized Mean Bias greater than +/- 50 percent • Normalized Mean Error greater than 50 percent Where bias and error are calculated for cases when the observed concentrations are greater than or equal 10 percent of the maximum observed concentration for each species. The differences between predicted and observed PM_{10} chemical component fractions are subjectively determined to be significant, and cannot be explained or significantly reduced through diagnostic analysis. Significant differences in the relative contributions of primary and secondary PM_{10} exist between observations and predictions.
Graphical	Modeled and observed species for the episode are not spatially and/or temporally consistent. Diurnal variation of the predicted sum of nonvolatile PM components is not consistent with TEOM observations. Observations and predictions of primary and/or secondary species appear spatially uncorrelated and the lack of correlation cannot be explained. Spatial and/or temporal differences can be explained but indicate significant problems with the meteorological, emissions, or other inputs to the model.
Sensitivity	Response for secondary species is inconsistent with our understanding of the processes leading to their formation as described by a conceptual model developed in the scoping study. Initial or boundary conditions dominate model predictions of primary and/or secondary species. Model predictions of secondary species are unresponsive to changes in precursor emissions.
Data	Type and/or quantity are insufficient to perform statistical and graphical tests indicated above.

It must be stressed that these rejection criteria may change as we carry out the evaluation. In this type of evaluation where data are limited, the process, rather than specific criteria, leads to rejection or acceptance. The process will be an iterative one in which we first identify failures in model performance and then use the information obtained in our analysis to improve the model configuration or inputs. We would then rerun and re-evaluate model. Final rejection of the modeling would only come if, considering schedule and resources, all reasonable improvements are exhausted. Because the evaluation will be carried out by chemical component, performance for primary and secondary PM_{10} may be accepted or rejected independently.

In addition to evaluation of model results in terms of the above rejection criteria, base case model results must also be examined in terms of diagnosing the model's limitations. Examples of some potential model limitations are:

- inability of model to accurately treat light and variable winds which may lead to anomalous concentrations in areas of wind convergence;
- inability of model to trap pollutants within the inversion layer due to terrain following coordinate system, etc.

The process of understanding the limitations of the base case modeling runs will inform our performance criteria decisions.

6.3 Model Performance Evaluation Methods and Issues

In this section, we discuss how a model performance evaluation would be carried out for an absolute attainment demonstration and what problems are likely to be encountered in a practical evaluation. This is an idealized view of methods and criteria, some of which are not applicable to the PM_{10} aerosol modeling study because of insufficient data.

6.3.1 Statistical Evaluation

To quantify base-case model performance, selected statistical calculations are prescribed to compare observed and simulated pollutant species concentrations at monitoring sites for which valid, representative data are available (Tesche et al., 1990). Simulated pollutant concentrations for each monitoring site should be calculated by linearly interpolating pollutant concentrations from the center of each of the four adjacent grid cells. All statistics should be calculated for each monitoring site for which observed concentrations are available, for each county, and for all monitoring sites within the modeling domain. Statistics will be calculated for all chemical species for which observations are available. Three statistical measures of model performance are recommended in the existing EPA guidance document.

1. Mean normalized bias (NBIAS in percent) where N includes all of the predicted (Pred) and observed (Obs) concentration pairs with observed concentrations above a threshold concentration from all stations in a region (or subregion) on a given day. Note the bias is defined as a positive quantity when the model estimate exceeds the observation.

$$NBIAS = \frac{100}{N} \sum_{i=1}^{N} \frac{(Pred_{x,t}^{i} - Obs_{x,t}^{i})}{Obs_{x,t}^{i}}$$

2. Mean normalized error (NERROR in percent)

$$NERROR = \frac{100}{N}\sum_{i=1}^{N}\frac{|Pred_{x,t}^{i} - Obs_{x,t}^{i}|}{Obs_{x,t}^{i}}$$

3. Accuracy of daily maximum concentrations at the station with the highest observed concentration unpaired in time (APEAK in percent)

$$APEAK = 100\left(\frac{\text{Max } Pred_{xmax} - \text{Max } Obs_{xmax}}{\text{Max } Obs_{xmax}}\right)$$

These three statistics cover the basic concerns for model bias and error for all hours with concentrations above a background concentration and for model bias in the maximum concentration, which is particularly important for regulatory purposes for ozone.

Additional statistics that we have found useful and have included in prior evaluations are:

- Mean absolute bias
- Mean fractional bias
- Mean absolute error
- Mean fractional error
- Average accuracy of the daily maximum concentrations paired in space, unpaired in time
- Peak accuracy paired in space
- Peak accuracy paired in space and time
- Correlation of all hourly (or multi-hour) concentrations
- Correlation of daily maximum concentrations

These performance measures provide additional information regarding model performance and allow one to make statistical statements concerning the bias and error on an absolute basis and the amount of the observed variance (R^2) explained by the model predictions. The fractional bias and error are particularly useful for precursor species where large residuals often make it difficult to interpret the normalized and absolute bias alone. Examination of the peak accuracy paired in space and paired in space and time also provides insight to the spatial and temporal displacements of peaks that are common in photochemical simulations. Small displacements are expected because of uncertainties in the wind fields, but large displacements are symptomatic of problems. Often the three measures of bias or error (mean absolute, mean normalized, and mean fractional) provide redundant information; however, they still need to be examined for the occasional cases where they show significant differences and illustrate problems in the simulations.

In past air quality modeling studies, emphasis has been placed on statistical evaluation, as described above. However, in this study there will be only a limited number of observations with which to evaluate model performance. Therefore, we must take care not to overestimate the significance of these statistics.

6.3.2 Graphical Evaluation

Spatial pattern comparisons of predicted and observed ozone concentrations will be included as a performance measure. Time-series plots and contour plots (ground-level isopleths) are very useful for displaying simulation results. Graphical analysis procedures to be used include:

- Time-series plots comparing observed and simulated pollutant concentrations for all monitoring stations within the modeling domain. Observed values will be represented as points and simulation results as a line.
- Time-series plots comparing observed concentrations with the minimum and maximum simulated concentrations in surrounding grid cells of a monitoring site
- Contour plots showing simulated pollutant concentrations and observed concentrations for each hour and/or multi-hour interval.
- Tile plots showing differences between observed and simulated concentrations
- Tile plots showing differences between sensitivity simulations (see next section) and base-case simulations.
- Plots of the frequency distribution of residuals (differences between hourly observed and predicted concentrations).
- Plots of residuals versus observed concentrations.
- Scatter plots of observed versus predicted hourly concentrations.

6.3.3 Sensitivity Analysis

We define sensitivity analysis as an evaluation of the response of the model to variations in one or more of the model inputs. The purpose of sensitivity analysis is to determine which of the model inputs have significant impact on model output. Sensitivity analysis serves as a check on the air quality simulation by ensuring that the model behavior adequately reflects understood atmospheric and chemical processes.

The response of the photochemical grid model, represented by simulated pollutant concentrations at selected monitoring sites, will be evaluated as input boundary conditions and emissions rates are varied. Possible sensitivity simulations include:

- Zero initial conditions
- Zero boundary conditions
- Zero anthropogenic emissions
- Zero and double particulate matter emissions

- Zero and double ammonia emissions
- Emissions reductions of 50 percent in nitrogen oxides
- Emissions reductions of 50 percent in reactive organic gases
- Emissions reductions of 50 percent in nitrogen oxides and in reactive organic gases
- Zero and double mobile source emissions
- Zero surface deposition

For each input scenario, graphical and statistical analyses will be generated.

6.4 Software

The statistical and graphical analyses for this MPE will be generated using the Package for Analysis and Visualization of Environmental data (PAVE) (Thorpe et al., 1996), ArcInfo, and the Model Performance Evaluation, Analysis and Plotting Software (MAPS) (McNally and Tesche, 1993).

PAVE will be used for graphical exploration model simulation results and producing tile plots. A set of utility programs, developed at the California Air Resources Board, will be used to extract data from the UAM-AERO output files for use with ArcInfo and other analysis tools.
The MAPS system includes all of the recommended statistical and graphical analysis methods suggested for photochemical models by Tesche et al., (1990) and will be used by STI scientists in their evaluations of model performance.

7.0 PM_{10} MAINTENANCE DEMONSTRATION

Projection year model results will be used to demonstrate PM_{10} NAAQS attainment during winter-time inversion events for the years 2005 through 2015. Section 7 outlines the technical procedures that will be used to apply the model results to the demonstration of maintenance.

7.1 Boundary Conditions

The Wasatch Front represents a small urban corridor in the middle of the rural Great Basin. Background levels of pollutants are small compared to locations in the central and eastern United States where upwind sources are highly significant. Background chemistry source regions for the Wasatch Front potentially include Washington, Oregon, and Northern California.

At the time of this modeling work there have been no field or regional scale modeling studies that have provided estimates of background boundary conditions for use in the UAM-AERO model. Background boundary conditions for the base case and projection year modeling will be selected based on western United States estimates. These values are deemed adequate because winter-time inversion chemistry is generated locally within the valley’s inversion. Synoptic scale meteorological forcing during inversion events is weak and acts to limit regional scale transport of precursor or primary PM_{10} chemistry.

7.2 Relative Reduction Factors

Draft modeling guidance for $PM_{2.5}$ issued by the EPA in 2000 suggests that air quality modeling results have many inherent uncertainties. As a result, model outputs should be used in a "relative" sense rather than and "absolute" sense. The $PM_{2.5}$ guidance outlines a method whereby component specific relative reduction factors (RRFs) are developed for the evaluation of modeled projection year attainment using "relative" model results (U.S. EPA, 2000).

The UDAQ attainment demonstration evaluates PM_{10} attainment, however, an analysis of Wasatch Front PM_{10} data has shown that 60% to 85% of PM_{10} falls within the $PM_{2.5}$ size fraction. Therefore, the RRF method suggested in the EPA $PM_{2.5}$ guidance is relevant and appropriate for the PM_{10} maintenance modeling demonstration.

7.2.1 Development of Relative Reduction Factors

The development of RRF formulations for the UDAQ attainment demonstration will be completed using the EPA guidance, experience gained from completed PM modeling projects, and analysis of the selected modeling episodes. The specific RRF formulation that will be applied will incorporate the major principles outlined in EPA's guidance, however, formulation details will vary to accommodate the unique winter-time meteorology of the Wasatch Front.

MODEL PREDICTION VALUES

The geography of the Salt Lake Valley (SLV) forces abrupt land-use changes along the valley's east, west, and north sides. The abrupt change of land-use has implications for emissions and resultant PM10 in each of the UAM-AERO 4-km model grid cells. The SLV urban corridor is constrained to a width of only 3 model grid cells and a length of 7 model grid cells. Previous PM modeling experience has shown that the grid cells containing the highest concentrations of PM are limited to an even narrower 1 to 2 grid cell wide band along the center of the valley.

Many modeling applications have utilized 4-cell averaging and 4-cell interpolation of the model output to estimate model concentrations at a monitor. This approach is valid in applications where the urban land-use and coincident high PM_{10} concentrations areas are spread over numerous model grid cells. In the SLV application, averaging and interpolation may produce PM concentrations that are influenced by abrupt land-use transition from urban high emission cells to rural low emission cells. These methods will smooth the highest grid cells to reflect lower PM concentrations. A more conservative approach that retains the highest concentrations of model PM10 is to use single cell model results. Therefore, model PM_{10} concentrations at monitor locations will be estimated using the co-located model grid cell concentration. Single cell model concentrations will also be used for all cells not co-located with a monitor.

TOTAL PM10 RELATIVE REDUCTION FACTORS

EPA guidance suggests breaking PM_{10} into 6 major constituent species categories (nitrates, sulfates, organic carbon, elemental carbon, primary inorganic particulate matter, unidentified mass) in order to develop species specific RRFs. In the case of the Wasatch Front, unique winter-time meteorology presents severe challenges for the simulation of PM_{10} through secondary chemistry. These challenges are expected to prevent UAM-AERO from capturing the individual concentrations of constituent species with great accuracy. UDAQ anticipates developing RRFs for total PM_{10} only, thereby removing the potential for model bias produced by RRFs applied to constituent species.

EPISODE AVERAGE RELATIVE REDUCTION FACTORS

UDAQ will use episode average RRFs for each PM_{10} monitor. Average RRFs will be used because Wasatch Front PM modeling has shown that model performance during an episode can vary widely from day to day. Most PM_{10} episodes build in a non-linear fashion throughout a multi-day inversion event. As an episode develops, slight changes in wind speed, fog, temperature, and mixing height lead to fluctuations in the rate of PM_{10} concentration build up. Meso-scale models are not capable of simulating these subtle meteorological changes that the Wasatch Front experiences. As a result, Wasatch Front modeling results have shown that during the simulation of PM_{10} episodes model performance can vary significantly from day to day as small meteorological changes affect the observations but are not simulated by the model.

UDAQ will develop episode average RRFs using all model-observation pairs with the exception of the first modeled day. The first modeled day will not be included to allow for model "spin-up" time. Using the remaining days, episode average RRFs will be calculated for each PM monitor. The average RRF approach will eliminate isolated daily model performance failures that are influenced by small meteorological fluctuations that are not simulated by the model. These spurious performance failures are not representative of the episode performance and do not necessarily reflect the model's ability to simulate maximum PM_{10} concentrations during an episode.

7.2.2 Formulation of Relative Reduction Factors

Three steps will be required to produce monitor specific RRFs:

1. Calculate Daily RRFs:

   An RRF will be calculated for each day after the day 1 model "spin-up" day. The RRF will be calculated as follows:

   $$RRF_{(Day)} = \text{Observed } PM_{10\,(Day)} / \text{Base Case } PM_{10} \text{ Model Result}_{(Day)}$$

2. Calculate Average RRFs:

$$RRF_{Average} = \sum RRF_{(Day)} / \text{Number of Days Utilized}$$

3. Calculate Projection Year PM_{10}:

$$\text{Attainment Test } PM_{10\ Projection\ (Day)} = RRF_{Average} * \text{Projection Year } PM_{10} \text{ Model Result}_{(Day)}$$

Consider an example PM_{10} attainment test calculation. During the February 2002 episode, 24-hr average PM_{10} was measured at the Cottonwood monitor (CW) on February 1, 4, and 7. For each of the 3 days, an RRF will be calculated according to Step 1. For example, on February 4 the measured PM10 at CW was 84.5 ug/m3. If we assume that the base year model PM10 prediction for CW was 94.0 ug/m3 then the RRF value would be calculated as 84.5/94.0 producing 0.89. This calculation would also be done for February 1 and February 7 producing 3 unique RRF values.

According to Step 2, the 3 RRF values will be averaged to produce one average RRF value for the CW monitor. Hypothetically, we can assume that CW's average RRF value is 1.03. This average RRF value will be applied to a projection year model value to produce the attainment test PM_{10} value (Step 3). Hypothetically assume that the 2005 projection year PM_{10} model value for the grid-cell that is co-located with the CW monitor is 135.6 ug/m3. The attainment test PM_{10} value will be 135.6 * 1.03 giving a final value of 139.7 ug/m3. This value is less than 150 ug/m3 and would pass the attainment test.

7.2.3 Application of Relative Reduction Factors

The evaluation of modeled PM concentrations at each monitor will utilize the single grid cell within which the monitor is located. The monitor specific RRF will be applied to that grid cell. Grid cells that are not co-located with a monitor will use the RRF developed for the monitor that lies closest to the center of the given grid cell. RRF adjusted grid cells will be evaluated for PM_{10} attainment using a maximum concentration criteria of 150 ug/m3. PM_{10} attainment will be evaluated for each projection year.

7.3 Hot Spot Analysis

The modeled attainment test for PM_{10}, whether using a relative or absolute approach, has no ability to evaluate attainment at locations where there is no nearby monitor. Consequently, DAQ proposes to use a Hot Spot Analysis, similar to that discussed in EPA's "Guidance for Demonstrating Attainment of Air Quality Goals for $PM_{2.5}$ and Regional Haze" (Draft, March 27, 2000). DAQ recognizes that EPA's guidance document is specific to $PM_{2.5}$ but DAQ believes that this analysis will be robust for PM_{10} because the hot spot analysis relies on emissions of primary particulates which are often larger than 2.5 microns.

The hot spot analysis will focus on large sources of primary PM_{10}. Whereas secondary PM_{10} tends to be spatially uniform, localized areas of primary PM_{10} can be linked to particular sources of primary particulates. Consequently, we believe that the monitoring network can accurately represent secondary particulate concentrations, but there may be locations within the nonattainment areas that do not have nearby monitors which might have higher primary PM_{10} concentrations than the distant monitors represent.

In order to proceed with the hot spot analysis for the Wasatch Front nonattainment areas (Salt Lake County and Utah County) we will make a couple of initial assumptions. The 4-km x 4-km UAM-AERO grid will be aggregated into an 8-km x 8-km grid. This assumes that primary particulate sources impact an area greater than 4-km x 4-km. Since the hot spot analysis will be used in conjunction with the modeled attainment demonstration, we will use the 2015 emissions inventory which will be developed for the UAM-AERO future year modeled attainment demonstration. This inventory will include growth from 2001 and will also include allowable emissions for the largest point sources.

The hot spot analysis will include the following steps:

- Evaluate the primary particulate emissions (from the 2015 future year projection inventory) in each 8-km grid cell in the nonattainment areas (Salt Lake County and Utah County) which has a PM_{10} monitor.
- Evaluate whether there are any grid cells within the nonattainment areas which do not contain a monitor and which have primary particulate emissions greater than those of any grid cell containing a PM_{10} monitor.
- Evaluate the emissions sources within those grid cells which have higher primary PM_{10} emissions than those in grid cells containing PM_{10} monitors. If there is a single point source within any of those grid cells which accounts for more than 50% of the primary PM_{10} emissions in that grid cell, then that point source should be flagged for a hot spot analysis. Because we are interested in demonstrating maintenance of the NAAQS through 2015, the emissions used for this analysis will be the emissions inventory which will be developed for UAM-AERO for the 2015 future year projection. We will also evaluate the domain for areas where there are multiple point sources within a single grid cell or that have high area or mobile emissions. However, preliminary review of the 2001 emissions inventory indicates that aggregation of area, point and mobile sources is very unlikely to trigger a hot spot analysis based on the above criteria.
- Apply a point source model to a flagged source for the months of January 2001 and February 2002 in order to demonstrate compliance with the 24-hour PM_{10} NAAQS. We are using this hot spot analysis in conjunction with episodic modeling for two wintertime episodes in 2001 and 2002. Consequently, we want to represent hot spot impacts during this same time period relative to meteorology, operating conditions and emissions. We will use the highest 24-hour average concentration from both the January 2001 and February 2002 episodes for evaluation of the 24-hour PM_{10} NAAQS. It is likely that CALPUFF will be the model of choice for this point source evaluation because CALPUFF can be used under stagnant wind conditions (which are present during wintertime inversions).
- In order to evaluate the impact of the flagged source on the PM_{10} NAAQS, we must also

evaluate the background primary and secondary PM_{10} in the grid cell of the highest hot spot impact. Since we are modeling a particular wintertime period using UAM-AERO, we will determine the secondary particulate component by evaluating monitored secondary PM_{10} in Utah and Salt Lake Counties during our two modeled wintertime episodes (in this case, January 1-10, 2002 and February 1-8, 2002). We are assuming that secondary particulates are relatively uniform throughout each air basin, so we will take an average of monitored secondary PM_{10} concentrations in either Utah or Salt Lake County (depending on whether the hot spot is located in Utah County or in Salt Lake County) during the episodes. This value for secondary PM_{10} will be added to the highest 24-hour concentration of primary PM_{10} obtained from the point source modeling. In addition, a background concentration of primary PM_{10} will be added to the above sum. The background concentration, in this case, will be obtained from monitored PM_{10} concentrations at Grantsville in Tooele County during January 2001 and February 2002. This site is likely to include typical background anthropogenic PM_{10} concentrations which are similar to outlying areas of Utah County and Salt Lake County.

- If the PM_{10} concentrations obtained from the above analysis exceed the level specified in the NAAQS (150 $\mu g/m^3$), then remedial measures are needed for hot spot point sources when designing future year control strategies.

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