ARMY RESEARCH LABORATORY

Air Mass Forecasts Using the Mesoscale Model Version 5 (MM5)

by Jeff Passner

ARL-TR-4032 **January 2007**

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Army Research Laboratory
White Sands Missile Range, NM 88002-5501

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14. ABSTRACT

Weather can play a significant role in military planning and operations; thus, the U.S. Army Research Laboratory has developed a number of decision aids to optimize the use of weather conditions and forecasts in the battlefield. These weather variables are most often derived from mesoscale weather models, which provide weather forecast information from 0 to 48 h. The most basic variables, such as temperature, moisture, and wind data, are output from the model directly, but many of the decision aids need more sophisticated information for their systems, such as icing, turbulence, and air mass type. This study will investigate the relationship between model output and air mass forecasts. The model used is the Fifth-Generation National Center for Atmospheric Research (NCAR)/Penn State Mesoscale Model (MM5), which was centered on the urban, complex terrain of Salt Lake City, UT.

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Summary

Weather can play a significant role in military planning and operations; thus, the U.S. Army Research Laboratory has developed a number of decision aids to optimize the use of weather conditions and forecasts in the battlefield. These decision aids, such as the Integrated Weather Effects Decision Aid (IWEDA) and the Target Acquisition Weapons Software (TAWS), utilize many different weather forecast elements for either rule-based systems or physics-based systems. These weather variables are most often derived from mesoscale weather models, which provide weather forecast information from 0 to 48 h. The most basic variables, such as temperature, moisture, and wind data, are output from the model directly, but many of the decision aids need more sophisticated information for their systems, such as icing, turbulence, and air mass type. This study will investigate the relationship between model output and air mass forecasts. The model used is the Fifth-Generation National Center for Atmospheric Research (NCAR)/ Penn State Mesoscale Model (MM5), which was centered on the urban, complex terrain of Salt Lake City, UT.

1. Introduction

Weather can play a significant role in military planning and operations; thus, the U.S. Army Research Laboratory (ARL) has developed a number of decision aids to optimize the use of weather. These decision aids, such as the Integrated Weather Effects Decision Aid (IWEDA) and the Target Acquisition Weapons Software (TAWS), utilize many different weather parameters for either rule-based systems or physics-based systems. Weather variables, such as temperature, moisture, and wind data, are derived from the Fifth-Generation NCAR/Penn State Mesoscale Model (MM5); however, many of the decision aids need more detailed weather information for their systems, such as icing, turbulence, and air mass type. This study will investigate the relationship between model output and air mass forecasts. The model was centered on the urban, complex terrain of Salt Lake City, UT, to validate the model and air mass forecasts and compare them to output provided by the Utah Air Monitoring Center.

2. Research of Dust and Aerosol Models

There have been numerous attempts to model aerosols and dust production from many groups. Most of these efforts come from Government researchers who are particularly motivated to study and display air-quality or air-pollution conditions and forecasts. The National Oceanic and Atmospheric Administration (NOAA) has developed the Real-Time Environmental Applications and Display System, which accesses and displays meteorological data and runs a trajectory and dispersion model (*1*).

One of the more recent efforts in the prediction of air quality has been using a real-time simulation of the Weather Research and Forecasting (WRF) model, which is called WRF-Chem and runs a 36-km air quality forecast out to 72 h. The chemistry package consists of many options of both biogenic emissions and anthrogenic sources of pollutants, as well as several choices of aerosols schemes. The model uses dry deposition coupled with a soil and vegetation scheme. (*2*)

The effort to run weather models and forecast air quality is a worldwide problem and many Government and university scientists have made an effort to run models to forecast dust and aerosols. The Dust Regional Atmospheric Model (DREAM), produced by the Earth Sciences Division of the Barcelona Supercomputing Center, predicts the life cycle of the eroded desert dust using the National Centers of Environmental Prediction's Eta model. Its main components are dust production with an introduced viscous sub-layer; particle size distribution effects; soil wetness effects on dust production; dry and wet deposition; and horizontal and vertical advection of turbulent and lateral diffusion (*3*).

However, of most concern to the ARL are the effects of aerosols and dust on military operations. Both the Navy Research Laboratory (NRL) and the Air Force Weather Agency (AFWA) have approached this problem.

2.1 Navy Aerosol Analysis and Prediction System (NAAPS)

NRL has developed the NAAPS, which is a global aerosol model. The model uses meteorological fields from the Navy Operational Global Atmospheric Prediction System (NOGAPS) analysis and forecast on a 1×1° grid at 6-h intervals using 24 vertical levels to 100 hPa. The main emphasis of the NAAPS is on sulfur, dust, and smoke emissions. (*4*)

The sulfur dioxide emission is based on the Global Emissions Inventory Activity (version 1A) for the year 1985 with a seasonal variation and two-level vertical distribution. Smoke emissions are based on geostationary satellite and moderate resolution imaging fire products. Dust emission occurs whenever the friction velocity exceeds a threshold value, snow depth is less than a critical value, and the surface moisture is less than a critical value. The flux is taken from Westphal's work and includes only particles with radii smaller than 5 microns. (*5*)

2.2 AFWA's Dust Transport Application

Toon and Colarco developed the Community Aerosol Research Model for the National Aeronautics and Space Administration, Ames Research Center, which the Johns Hopkins University Applied Physics Laboratory modified to incorporate MM5 data from AFWA. AFWA renamed this model the Dust Transport Application (DTA), which is used operationally as it ingests 45-km MM5 data. The surface dust flux, which uses the MM5 surface wind output, is based on wind threshold velocity, which depends on particle diameter; air and particle density; and soil moisture. The soil moisture is determined by using the Agricultural Meteorological Model soil moisture output to determine soil wetness. When the MM5 indicates that precipitation is falling, it is assumed that there is no surface dust flux at a grid point. The DTA removes dust through wet deposition and accounts for atmospheric stability using a vertical wind parameter and vertical diffusion coefficient. The DTA uses a dust source region database developed by Ginoux. (*6*, *7*, *8*)

AFWA implemented the DTA onto the Joint Air Force and Army Weather Information Network in February 2003. In evaluations of the DTS, Wesley et al. (*9*) note that the DTA excels at forecasting synoptic-scale dust storms and dust storms that are generated by strong pressure gradients. The DTA model has difficulties with small-scale events and some mesoscale events, such as those generated by thunderstorms. Wind speed, atmospheric stability, and source region are the three main environmental factors in dust forecasting and the dust forecasts are highly dependent on season, soil type, vegetation, and surface heating.

3. ARL's Method

Unlike the requirements at NRL and AFWA, currently ARL Tactical Decision Aids (TDAs) do not require aerosol or dust forecasts. The main focus at ARL is on the air mass type; thus, there is no need for satellite data and some of the complex information needed by NAAPS and the DTA. This simplifies the problem greatly and permits a rudimentary solution in the initial effort to determine the air mass type. The three main aerosols of interest for this project are the rural, urban, and maritime aerosols (*10*):

- The rural aerosol is typically found in continental air masses. This aerosol is composed principally of sub-micrometer soil particles and products of certain natural and manmade processes occurring in continental regions.
- The urban model describes aerosols that include significant concentrations of particles produced in urban and industrial complexes. The chemical makeup of the aerosol is that of the rural aerosol plus an added component representing soot-like aerosols
- The maritime model characterizes aerosols that include sea-salt particles. This model should be used when the air mass is maritime and the target area is more than a few kilometers inland.

To determine which aerosol model is the dominating one at the initial time or some future forecast period, the output from the MM5 is used.

3.1 The MM5

The MM5 is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation (*11*).

Terrestrial and isobaric meteorological data are horizontally interpolated from a latitude-longitude mesh to a variable high-resolution domain on Mercator, Lambert Conformal, or polar stereographic projection. Since the interpolation does not provide mesoscale detail, these interpolated data may be enhanced with observations from the standard network of surface and rawinsonde stations, using either a Cressman or multiquadric scheme. In the MM5, there is also a program that performs the vertical interpolation from pressure levels to sigma coordinates. The sigma surfaces near the ground closely follow the terrain, while the higher-level sigma surfaces tend to approximate isobaric surfaces.

Other features of MM5 are that it is globally relocatable; has flexible, multiple nesting capabilities, advanced physical parameterization, and a three-dimensional data assimilation system via nudging; and can be run on various platforms.

The version of the MM5 being used in this study is version 3 from AFWA with a resolution of 15 km mesh data on 41 vertical levels. ARL receives these MM5 data in binary form for the continental United States twice each day, which are initialized at 0600 universal time coordinates (UTC) and 1800 UTC, respectively. Due to computational and processing constraints, there is a 6-h stagger between the initialization valid time of the 15-km mesh and the first forecast output; thus, the first MM5 forecast is a 6-h forecast. The frequency of the model output is every 3 h for a time period of 48 h.

The AFWA version of the MM5 places the lowest model vertical level at 20 magl. To generate data at the standard observation heights of 10 and 2 magl, similarity theory is being used at ARL to extrapolate to these lower levels from the lowest MM5 sigma level. In this fashion, temperature, dew point, and wind data at levels 2 and 10 magl are produced at ARL in addition to the 41 MM5 sigma levels of data.

The parameterizations selected by AFWA with this version of the MM5 are as follows:

1. Grell cumulus parameterization—Designed for grid sizes of 10 to 30 km, this parameterization accounts for sub-gridscale convection and compensating subsidence.
2. Medium Range Forecast (MRF) planetary boundary-layer (PBL) model—This model parameterizes the mixture of heat, moisture, and momentum in the boundary layer.
3. Reisner mixed phase explicit moisture microphysics—Cloud and rainwater fields and ice processes are predicted explicitly. No graupel or riming processes are calculated.
4. Dudhia cloud radiation—This parameter provides solar and infrared fluxes at the ground and atmospheric tendencies resulting from the radiative processes.
5. MM5 five-layer soil model.

3.2 Air Mass Routine Used at ARL

The original method for determining the aerosol model selection process used the Low Transmission Atmospheric Propagation code (LOWTRAN), which asked the user to answer a series of questions, such as how long the air mass had been over land or how far from an urban area a location was. One difficult feature of this software and program was that it involved human interface and it was often difficult to judge how long air parcels had been over land or water. Also, the definition of rural or urban was vague, given that the 8-km distance from the central business district was arbitrary from city to city. Additional complexities were that the MM5 did not indicate where the air mass originated and it was assumed that the boundary layer was considered 1.5 to 2.0 km above ground level (AGL) at all times. (*12*)

The method for air mass type in this project was based on the theories applied in the LOWTRAN method, but it was modified significantly for output from a mesoscale model. As a first test, the software determined if the air mass was marine or continental by checking the elevation and proximity to the ocean. In addition, if the rainfall rate was over 12.5 mm/h, it was assumed that this rainfall would effectively wash out the salt and it was considered a “continental” air mass.

If an air mass was determined to be continental, then the ARL software made a determination if the air mass was either rural or urban. This was a more complex assessment since the computer software had to estimate the inversion height and lapse rate below the inversion. To determine the inversion height, the program investigated the vertical structure of the atmosphere for significant layers of warming and determined if the height of the inversion level was not too close to ground or too high above the ground to trap significant amounts of aerosols. If there was no inversion, it was assumed that mixing was sufficient enough to disperse the aerosols and that the environment was considered as rural. The program then checked the vertical lapse and surface wind speed. The following three cases helped to determine if the air mass was urban or rural:

- Stable boundary-layer: Light winds (urban air mass), strong winds (rural air mass)
- Neutral boundary-layer: Light winds (urban air mass), strong winds (rural air mass)
- Unstable boundary-layer: All wind speeds, considered rural air mass

The final factor to determine if air mass types were urban or rural was the accumulated precipitation over the last three hours. If the precipitation from the model forecast was over 6.0 mm, then it was assumed that wet deposition was efficient and the air mass is rural. All terrain points over 2.0 km were considered rural.

4. Verification

Verification of the air mass routine was conducted by setting the MM5 grid over the Salt Lake City (SLC), UT, area and using data from the Utah Air Monitoring Center (AMC) to compare the particle matter (PM) readings to the air mass forecasts. Data were collected at Lindon, Ogden, and Logan, as well as in the Hawthorne area of SLC.

4.1 The Utah AMC

The Utah AMC is responsible for operating and maintaining an ambient air monitoring network that provides air pollution information for the daily Air Quality Index (AQI), health advisories, seasonal wood burn conditions, and summer ozone alerts. AMC data is used to determine the relationship of existing pollutant concentrations to the national air quality standards and to assist in reducing pollution levels. The pollutants of most interest in this study are particulate matter smaller than 10 microns (PM10, 1-h averaging time) and particulate matter smaller than 2.5 microns (PM2.5, 1-h averaging time). These data are available at a number of locations in and around the SLC area. In addition to air pollutants, many of the Utah sites provide information in wind direction, wind speed, relative humidity, temperature, and short-wave radiation in w/m^2. These data are available in plots that output data over a two-day period as displayed in figure 1. (*13*)

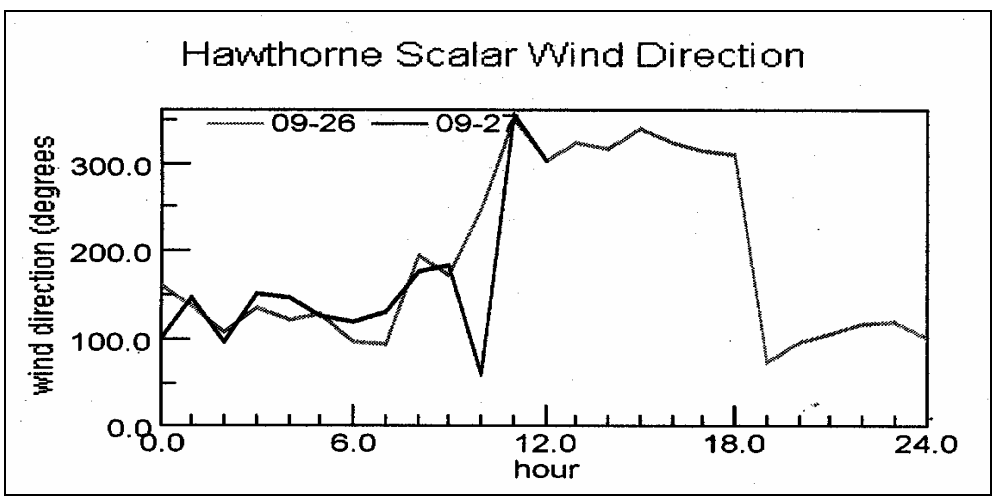

Figure 1. The plot of the wind direction in degrees from the Utah AMC program.

4.2 SLC Terrain

The Salt Lake Valley is a unique place to study meteorological models and meteorological conditions. The city is surrounded by higher terrain in all directions except the north where the Great Salt Lake is located. Additionally, the valley with a large population has become an intriguing region to study air pollution and aerosols, since the valley is often characterized by a stable boundary layer with a strong morning inversion. The complex terrain is also a challenge because of a variety of wind flows influenced by the mountains and the lake. The terrain is seen in figure 2.

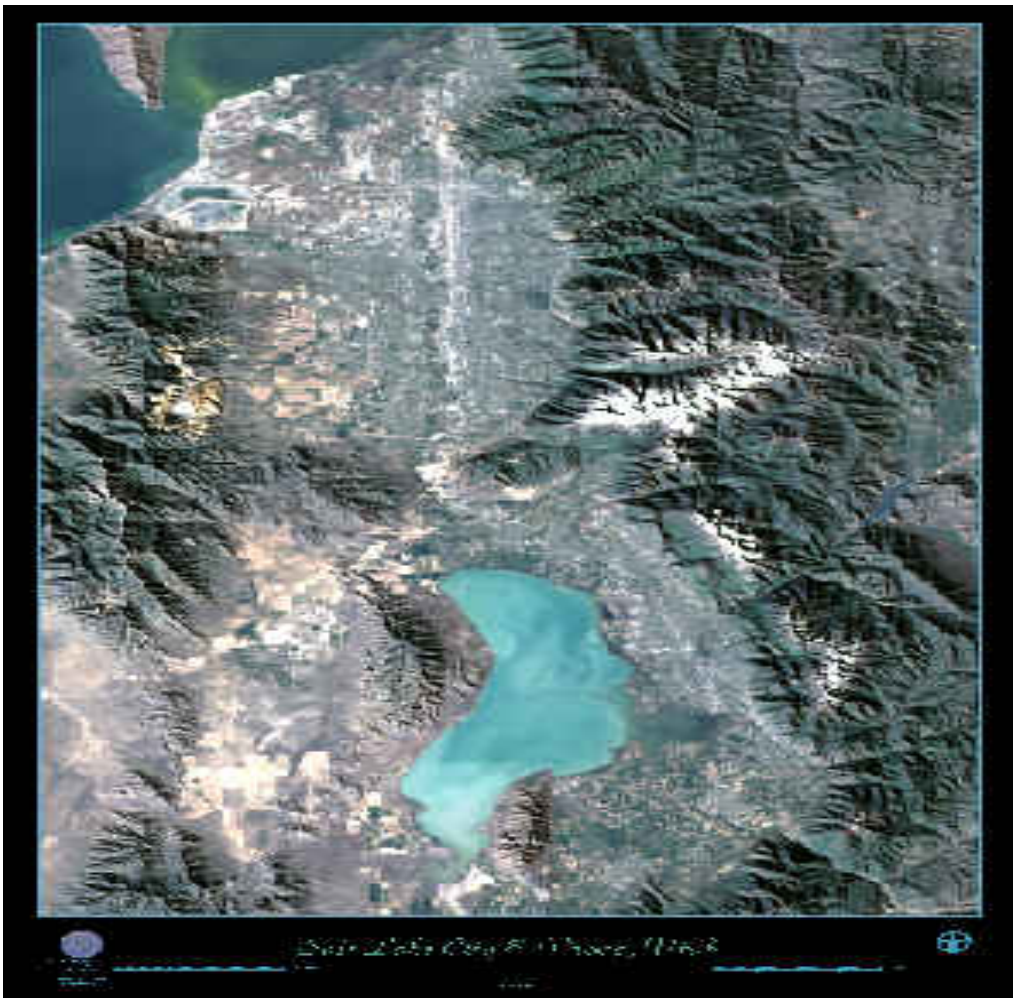

Figure 2. The complex, urban terrain of the Salt Lake Valley in Utah.

NOTE: Source: http://www.visitsaltlake.com/getting_around/maps.html.

4.3 MM5 Performance and Biases

As noted, the MM5 data from AFWA was used to model the meteorological conditions and provide forecast data for this study. The 0600 UTC models were used with the grid centered over urban SLC and forecast results were compared only for the 6- to 24-h forecast periods. Data was collected from January 2004 to May 2005.

In table 1, the results of the MM5 temperature, wind, temperature inversions, and radiation forecasts are shown for the Hawthorne area of SLC. The mean absolute difference (MAD) is the sum of the errors divided by the number of data points. The root mean square error (RMSE) is the square root of the mean square error and the correlation coefficient (CC) shows the strength of a linear relationship between two random variables.

Table 1. MM5 forecast skill at SLC from January 2004 to May 2005.

	Forecast Average	**Observed Average**	**MAD**	**RMSE**	**CC**
Temperature (°C)	2.7	5.9	3.9	5.0	0.88
Wind direction (°)	216	222	54	44	0.49
Wind speed (m/s)	4.3	3.1	2.2	3.1	0.38
Inversion height (m)	335	318	243	410	0.65
Short-wave radiation (w/m^2)	355	449	146	211	0.86

As might be expected in such a difficult forecasting domain, results of the MM5 forecasts through 18 h are not particularly good. The mean absolute difference in the temperature forecast were almost 4 °C, while the correlation coefficient was only 0.88. On average, the wind direction was in error by 54° in each forecast and wind speeds were about 2.2 m/s^{-1} in error. The incoming short-wave radiation forecast were generally underforecasted and inversion heights were on average 243 m different from the actual observations off the 1200 or 0000 UTC soundings from SLC.

The AFWA MM5 biases at Hawthorne were as follows:

- *Temperature*: The model underforecasts strongly between 1200 and 0000 UTC, with no bias noted at 0300 and 0600 UTC. Overall, the model underforecasts the temperature 78% of time (1 °C or more) from 1200 to 0000 UTC.
- *Wind Speed*: The model overforecasts (0.8 m/s or more) 70% of the cases at 1200 and 1500 UTC. No significant bias was observed at 1800, 2100, and 0000 UTC, but bias to overforecast wind speed starts again at 0300 UTC.
- *Wind Direction*: At 1200 UTC, the forecasts were 5° in error in the veering (clockwise) direction and had 26° veering of wind at 1500 UTC. In 65% of the cases, the forecasts displayed veering at 1500 UTC.
- *Inversions*: No high or low bias noted on inversion height. The “YES/NO” forecast displayed a probability of detection of an inversion 0.84, had a false alarm rate of 0.04, and correctly forecasting the non-event of 0.95.
- *Solar Radiation*: The MM5 underforecasts incoming short-wave radiation 71% of the time at 1500 and 2100 UTC. There was no model bias noted in late in the afternoon at 0000 UTC.

Of most concern for aerosol forecasts and air mass type is the forecasted wind speed. In table 2, the MM5 wind speed errors are shown for the 6- to 18-h forecast periods. The largest errors appear to be in the early morning hours when the downslope winds are dominating at 1200 and 1500 UTC. The error becomes smaller during the afternoon hours when the wind shifts to the

lake breeze (from the northwest or north) and then the error increases again late in day as the solar angle decreases. The CC of the wind is very low in the morning and late afternoon but very good during the late morning hours and mid-afternoon.

Table 2. MM5 wind speed error at Hawthorne site (m/s).

Forecast (time)	MAD (m/s)	RMSE (m/s)	CC (m/s)
6-h (1200 UTC)	2.7	3.0	0.16
9-h (1500 UTC)	2.7	3.4	0.28
12-h (1800 UTC)	1.6	2.1	0.76
15-h (2100 UTC)	1.4	1.7	0.81
18-h (0000 UTC)	2.4	2.8	-0.03

4.4 Discussion of Errors in the MM5

There are many reasons the forecasts may be in error, especially the temperature error. The first reason is, of course, related to using a 15-km grid, which can lead to significant errors in the model elevation due to the very steep gradient in the terrain just east of the location studied. There is evidence that the difference between the model terrain height and actual terrain height is 400 m. Another factor in the temperature error is the MRF PBL scheme. Long-term studies, such as Mass et al., show surface winds in the MRF PBL are too strong especially at night, low-level winds are too geostrophic, and there is too much vertical mixing. Traditionally, the MM5 is poor at forecasting temperatures in shallow cold air, which occurs in 85% of the 1200 UTC SLC soundings. Another factor that can cause model error is that the model spin-up can still cause forecasting problems at 1200 and 1500 UTC. (*14*)

4.5 SLC Air Mass Forecasts and Performance

An example of how the model and air mass forecasts interact is shown using the case of 13–14 February 2005.

A series of plots from the SLC AMC site shows how the PM10.0 and PM2.5 change during an interesting weather event in the Salt Lake Valley. As seen in figure 3, the concentration of PM2.5 drops steadily during this weather sequence. The values of PM2.5 for most of the day on 13 February 2005 are considered to be in the “moderate” range according to the AQI, although the PM2.5 values drop from about 35 $\mu g/m^3$ at midnight 13 February 2005 to near 10 $\mu g/m^3$ at midnight 14 February 2005 when the AQI category is considered “good.” Similarly, in figure 4, the readings of PM10 drop from about 30 $\mu g/m^3$ to near 10 $\mu g/m^3$ by midnight 14 February 2005. The PM10 values are considered to be “good” air quality. Thus, on this day, it appears that there is a larger amount of the smaller PM2.5, which is often associated with aerosols produced by local traffic, burning, and industry. These trends are also seen in figure 5, where the hourly plots of PM2.5 and PM10 are shown from 0300 to 1000 UTC on 14 February 2005. Based on these data, it appears that the decrease of the smaller PM2.5 pollutants decreases more than the larger PM10-sized particles. (*15*)

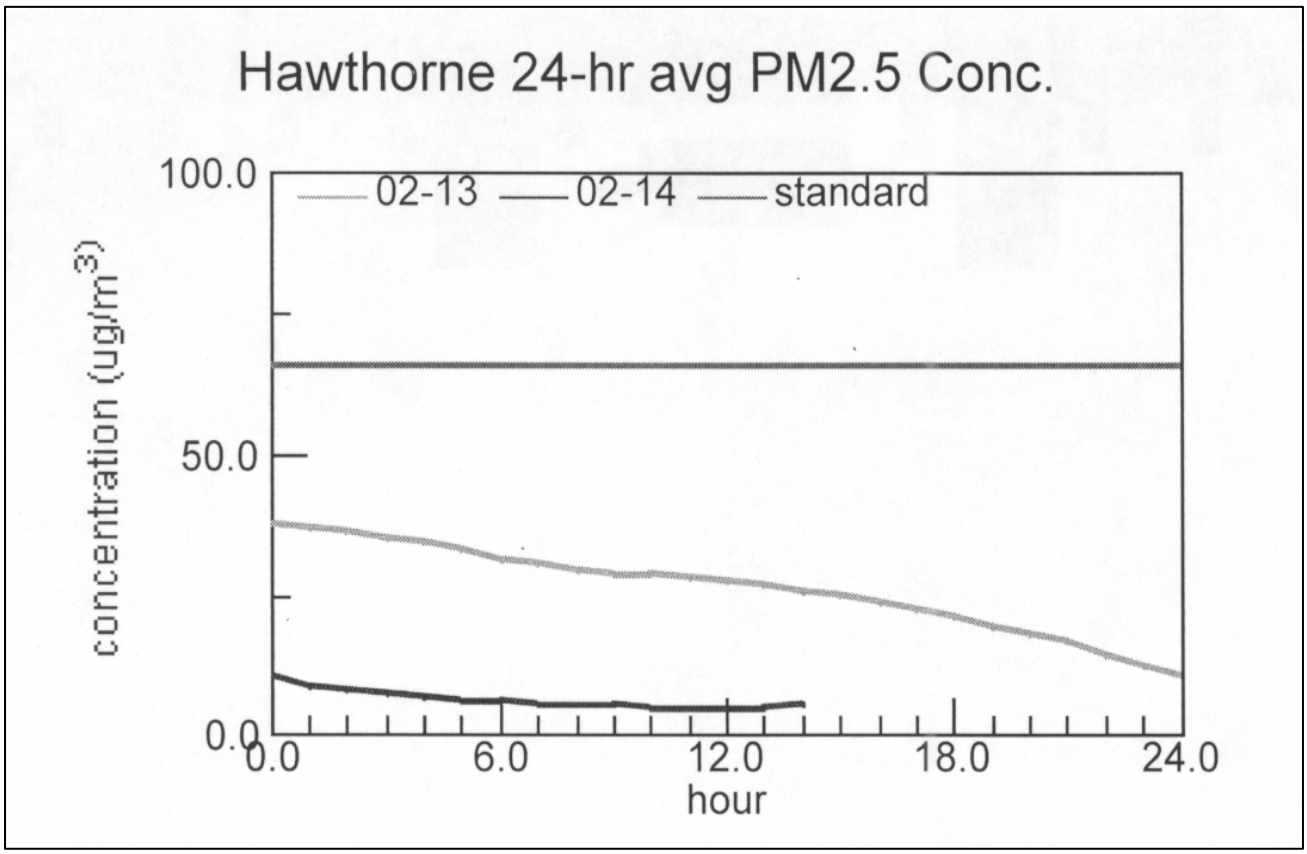

Figure 3. The trend in PM2.5 concentrations during a cold front event at SLC.

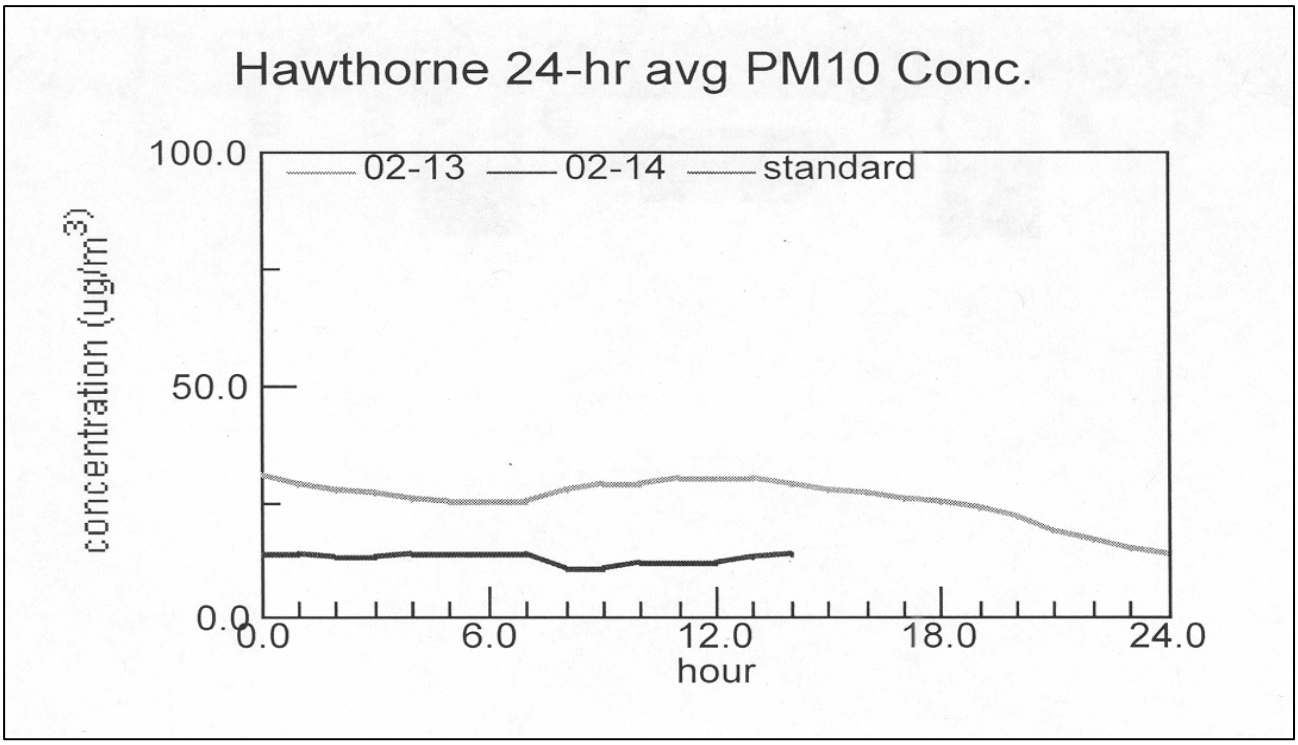

Figure 4. The trend in PM10 concentrations during a cold front event at SLC.

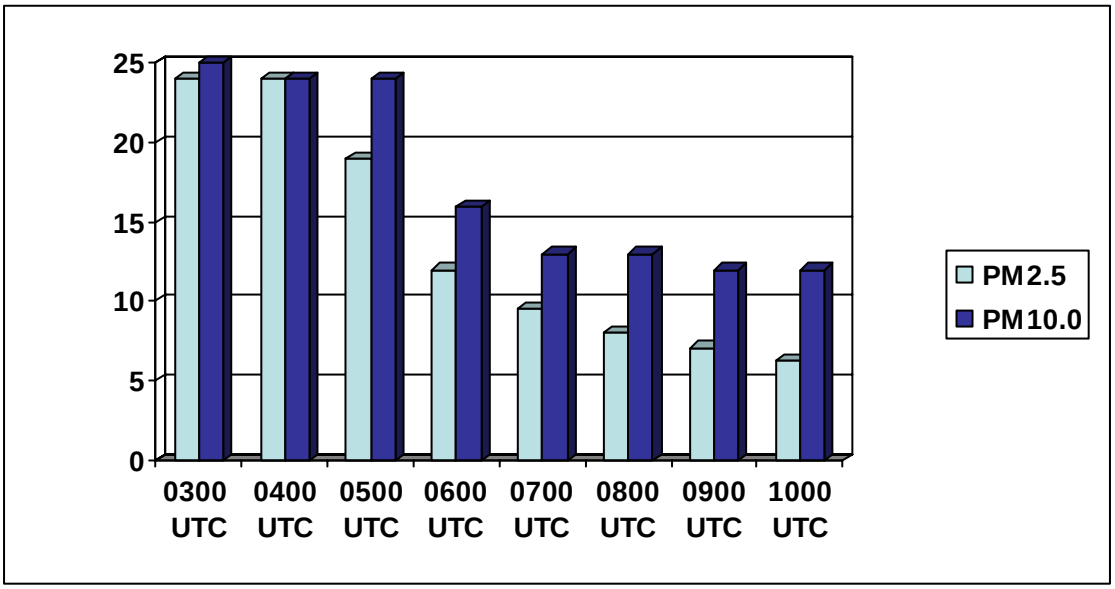

Figure 5. A look at how both the PM10 and PM2.5 change as the air mass changes.

It is interesting to try to relate the trends in the particulate matter to the observed weather. Figure 6 displays the wind direction during the two days studied. The timeframe in the plot is in local standard time (LST). The wind direction is generally from the south during the day on 13 February 2005, but shifts to the northwest or from the Great Salt Lake for a two-hour period between 1900 and 2100 LST (0200 and 0400 UTC 14 February 2005).

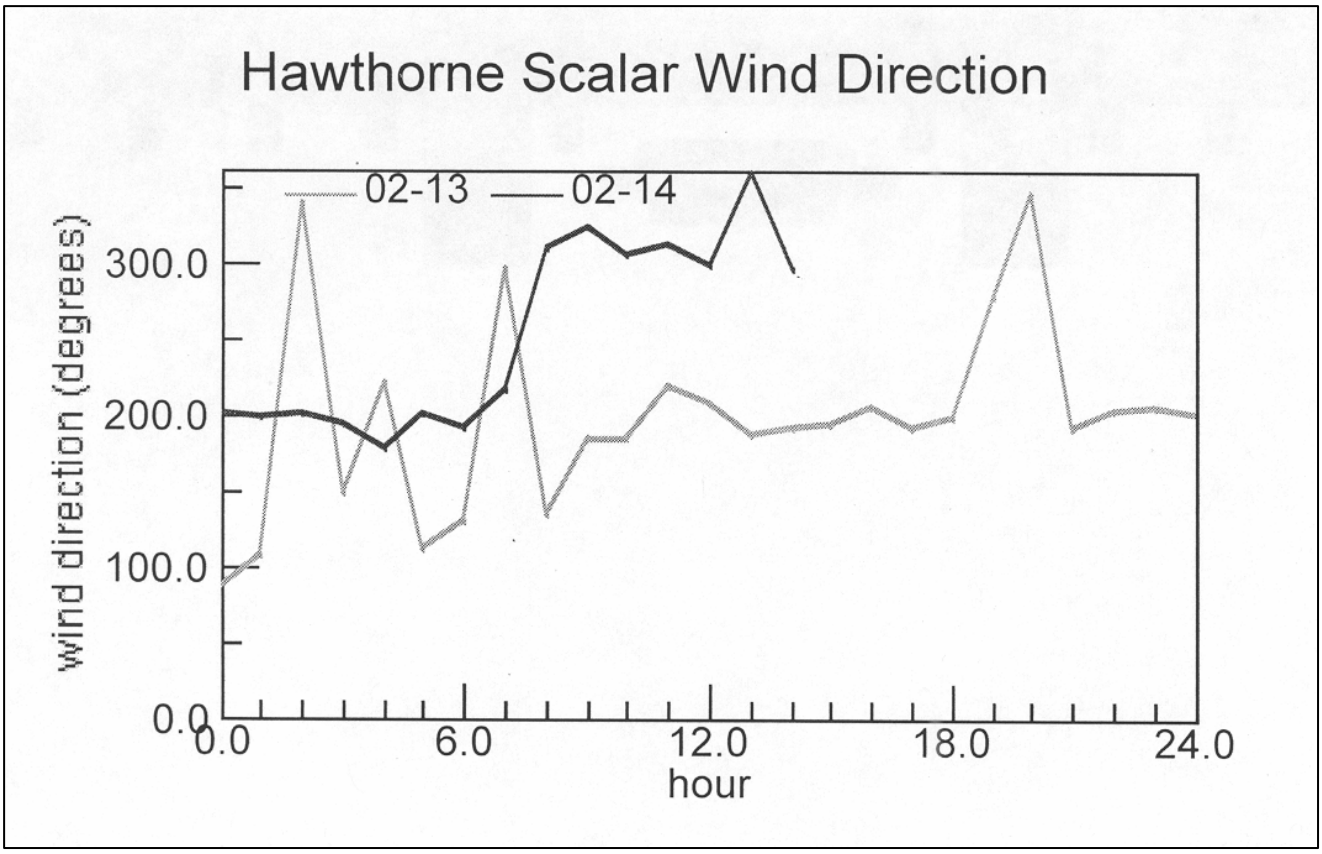

Figure 6. The wind shifts gradually from the south to northwest during the morning hours of 14 February 2005.

During time 1900 to 2100 LST timeframe, the wind speeds drop to 5 mph (2.2 m/s) as displayed in figure 7, but increase to 10 mph (4.5 m/s) when the wind shifts back to the south, a direction associated with the valley component of the wind. During the night, the dominating wind direction is from the south, but the wind shifts gradually to the southwest at 0800 LST (1500 UTC) and to the northwest at 0900 LST (1600 UTC), 14 February 2005. The surface pressure field and observed weather indicate that a synoptic-scale cold front passes through the region during the morning hours between 0600 and 0800 LST (1300 to 1500 UTC). This is seen by the wind shift as well as a pressure rise from 1013.6 hPa at 1100 UTC to 1015.6 hPa at 1700 UTC.

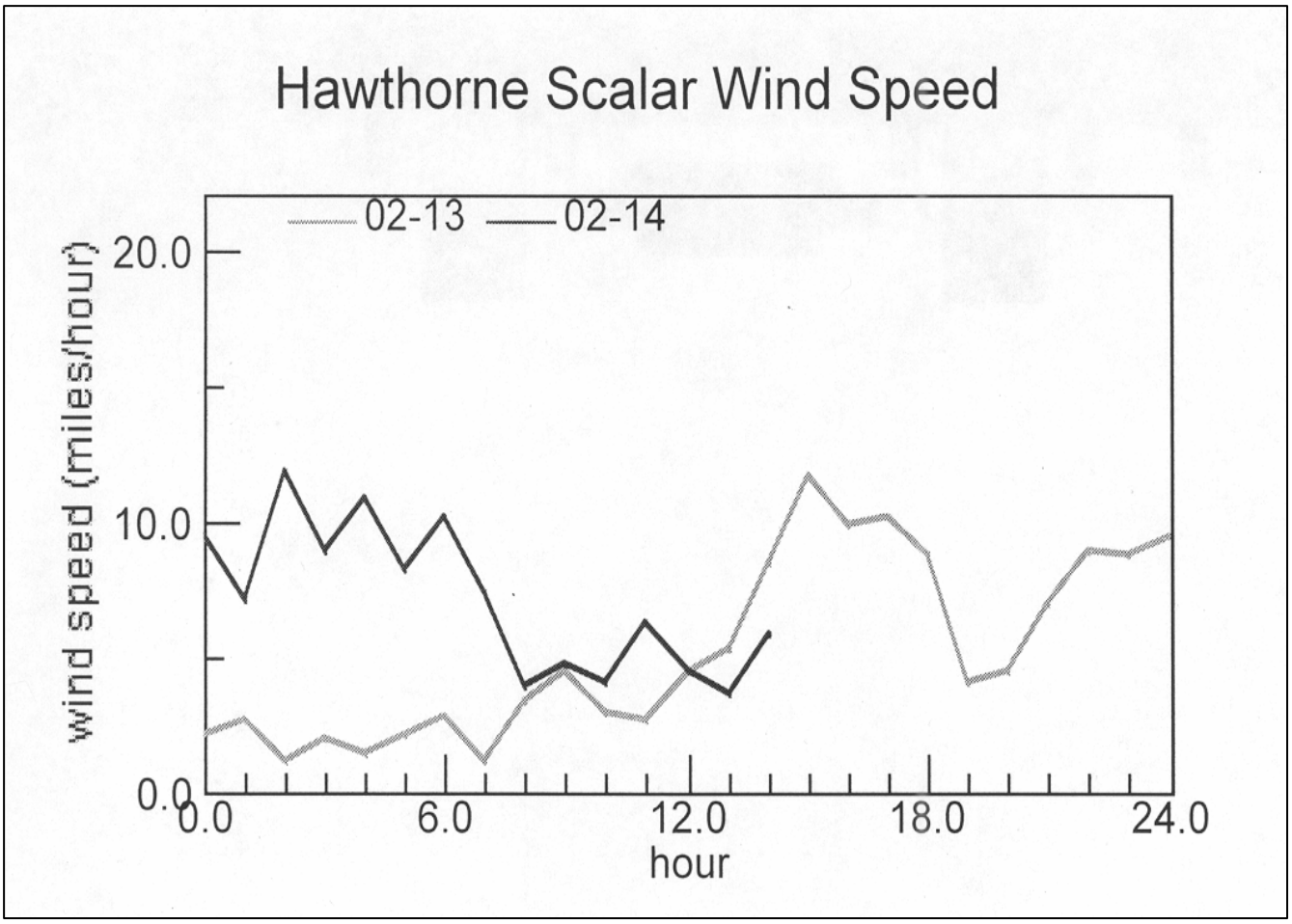

Figure 7. The wind speeds during the 13-14 February 2005 timeframe.

It is also intriguing to note that even with the cold frontal passage at about 0700 LST (1400 UTC), the reduction of particulate matter begins as much as 12 h before the cold front reaches the SLC area as seen in table 3. The temperature rises dramatically, from 2.8 °C to 8.9 °C in 2 h, as the winds shift from the cold water to the slight downslope direction from the south. This is also reflected in the relative humidity values, which drop from 89% to approximately 60% during the overnight hours. During the time period shown in table 3, the cloud height lowers and light rain is observed at the SLC airport at 0300 LST (1000 UTC), 14 February 2005. It is uncertain as to the exact reason the PM values decrease so quickly, but it can be assumed that there is significant vertical mixing even in the overnight hours due to the approaching weather system and perhaps some associated upper dynamical energy.

Table 3. The change in main weather parameters in the SLC area between 0300 and 1000 UTC, 14 February 2005.

Hour (UTC)	PM 2.5 (μg/m^3)	PM 10.0 (μg/m^3)	Visibility and Precipitation (mi)	Clouds (ft AGL)	Temperature (°C)	Relative Humidity (%)	Wind Direction	Wind Speed (m/s)
0300	24	25	10	110 BKN	2.8	89	340	2.2
0400	24	24	10	110 BKN	7.2	60	190	3.1
0500	19	24	10	100 BKN	8.9	56	200	4.5
0600	12	16	10	200 OVC	8.9	58	205	4.5
0700	9.5	13	10	100 BKN	8.9	60	200	4.5
0800	8	13	10	85 BKN	8.3	60	200	3.6
0900	7.1	12	10	65 BKN	8.3	60	200	5.4
1000	6.3	12	10R-	60 OVC	8.3	61	200	4.0

NOTE: BKN = broken ceiling and OVC = overcast ceiling.

As a final part of this case study, the MM5 forecast during this event was compared to the actual surface weather observations. Table 4 displays the model forecast for temperature, wind direction, wind speed, and air mass type.

Table 4. MM5 forecast and observations for temperature, wind, and air mass type at Hawthorne, UT, 14 February 2005.

Hour (UTC)	Temp Forecast (°C)	Temp Observed (°C)	Wind Direction Forecast (°)	Wind Direction Observed (°)	Wind Speed Forecast (m/s)	Wind Speed Observed (m/s)	Air Mass Forecast Type	Air Mass Observed (PM2.5)
0000 6-h forecast	6.5	9.4	208	190	4.5	5.9	Rural	25
0300 9-h forecast	4.5	2.8	173	340	8.6	3.0	Rural	23
0600 12-h forecast	3.7	8.9	195	205	7.6	5.9	Rural	16
0900 15-h forecast	2.8	8.3	216	200	5.6	7.1	Rural	7

As seen in table 4, this is a complex case where the wind direction forecast is significantly in error at the 9-h forecast (0300 UTC) as the forecast is from the south and the observed is from the northwest, or off the lake. This leads to cooler temperatures in the observation and the lower wind speed. By the 12-h forecast (0600 UTC), the forecast is correct again with the higher wind speeds, a slight downslope component in the valley, and an error to underforecast the temperatures. The air mass type is forecasted to be a rural type during the entire period due to the strong surface winds providing the mechanism to remove the PM2.5 out of the region.

Based on this study, the inversion "YES/NO" forecasts are very accurate. However, wind forecast bias at 1200 and 1500 UTC mean that air mass forecasts may show the least skill at that time and the most skill from 1800 to 2100 UTC.

In table 5, for PM2.5 any forecast or observation of less than 30 µg/m^3 was considered to be a rural forecast, while any forecast or observation of less than 55 µg/m^3 was considered rural for PM10. The results are what might be expected based on the MM5 forecast bias; the largest errors in the wind speed, as seen in table 2, are in the early morning hours from 1200 to 1500 UTC, where the absolute error is 2.7 m/s. Once the wind error decreases to an absolute error of about 1.5 m/s, as they do at 1800 and 2100 UTC, the accuracy of the PM2.5 and PM10 forecast increases dramatically before decreasing again at 0000 UTC, which is 18 h after model initialization. Still, the problem is not so simplistic. Typically the 1200 and 1500 UTC hours feature low-level inversions, especially in the cold season at SLC. While the MM5 provides an accurate vertical profile of the temperature profile, it does not always have an accurate forecast for when the inversion will break and the more "urban" air mass will mix out to become a "rural" air mass. However, an even more difficult task for this air mass program is that there is no current way of initializing the air mass at the start of the forecast. Obviously, the amount of particular matter at the start of the forecast period plays a major role in how the air mass type changes over the entire forecast cycle. Depending on just the forecasted weather parameters is an idealized solution to a difficult problem, but it does not provide a complete picture of how the air mass responds to the environmental conditions. Still, once the inversion does break, the air mass program does has a good feel for the transition from an "urban" or stable boundary layer to a more well-mixed or "rural" environment.

Table 5. Percent of correct forecast (rural or urban) using MM5 output at Hawthorne, UT.

Time/Size (UTC)	**PM2.5 (%)**	**PM10 (%)**
1200	29	32
1500	44	48
1800	78	74
2100	95	78
0000+	63	61
Total	63	61

NOTE: Randomly used values of <30 ug/m^3 as rural for PM2.5 and <55 ug/m^3 PM10 for 127 samples.

5. Conclusions

ARL has developed a number of decision aids to optimize the use of weather. These decision aids, such as the IWEDA and the TAWS, utilize many different weather parameters. In an effort to provide more detailed weather information for the TDAs, an air mass type program has been formulated using the output from the MM5. The MM5 was centered on the urban, complex terrain of SLC to validate the model and air mass forecasts and comparing them to output provided by the Utah AMC. This project approached two problems; the accuracy of the MM5 in the SLC area and the relationship between the model output and the air mass forecast.

The original approach to forecasting the air mass type was the LOWTRAN model, which determined if an air mass was urban, rural, or marine based on questions posed to the user. The current air mass forecast is an automated process, which is based on elevation, proximity to the ocean, rainfall rates, inversion heights, lapse rates, and wind speed at a model grid point. These factors then provided an air mass type as either marine, rural, or urban.

The MM5 results at Hawthorne, UT, were not encouraging, although this was expected given the 15-km resolution in a very complicated grid area that includes mountain ranges and a body of water. The mean absolute difference in wind speed was 2.2 m/s, the wind direction was 54° in error, the temperature forecast was 3.9 °C in error, and the inversion heights were 243 m different than the observation. It was found the largest wind speed errors were in the early morning hours and again near sunset (18-h forecast), while the wind speed forecast was most accurate at the 12- and 15-h forecast periods. Given the importance of the wind speed in the air mass forecast, it was found the air mass program had it highest verification at the same time that the wind speed forecasts were most accurate.

The method used in this effort was quite simplistic, and while it does provide accurate results after the morning inversion breaks, there is still much work needed in this research effort. A way to determine the air mass type at the model initialization would provide much-needed information that would help improve results. Data such as land-use, vegetation type, and soil moisture would enhance the model, especially for the PM10 output and dust forecasts. Improvement in the mixing height forecasts and the time that inversion breaks or forms would be useful additional input to the program. Additionally, wind gust information could help with the forecast for dust particles and its influence on the air mass.

A long-term goal would be to use the air mass type program and use the results in the visibility routine that are post processed. One other improvement would be to use the 2-km WRF model as the forecast output data. Using the smaller resolution would give additional terrain information, which should help the model in providing more accurate wind information and give significantly better forecast information for the air mass forecast.

Overall, the air mass program did provide good, basic guidance. The simple structure of the program can definitely be upgraded with more land-use information, better model resolution, and more information about the initial state of the atmosphere. These improvements can be added to future generations of the program.

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Acronyms

AFWA	Air Force Weather Agency
AGL	above ground level
AMC	Air Monitoring Center
AQI	Air Quality Index
ARL	U.S. Army Research Laboratory
BKN	broken ceiling
CC	correlation coefficient
DREAM	Dust Regional Atmospheric Model
DTA	Dust Transport Application
hPa	hecto-pascals
IWEDA	Integrated Weather Effects Decisions Aids
LOWTRAN	Low Transmission Atmospheric Propagation
LST	local standard time
MAD	mean absolute difference
MM5	Mesoscale Model Version 5
MRF	Medium Range Forecast
NAAPS	Navy Aerosol Analysis and prediction System
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NOGAPS	Naval Operational Global Atmospheric Prediction System
NRL	Navy Research Laboratory
OVC	overcast ceiling
PBL	planetary boundary layer
PM	particulate matter
PM10	particulate matter 10 microns or less
PM2.5	particulate matter 2.5 microns or less
RMSE	root mean square error
SLC	Salt Lake City
TAWS	Target Acquisition Weather Software

TDA	Tactical Decision Aid
UTC	universal time coordinate
WRF	Weather Research and Forecasting

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