EXECUTIVE SUMMARY

This final report describes work performed by the Department of Meteorology at the Pennsylvania State University under Grant Number 127617, 'Fairbanks North Star Borough PM2.5 Non-Attainment Area WRF-ARW Modeling', supported by the Alaska Department of Environmental Conservation (ADEC) and the Fairbanks / North Star Borough. The purpose of this project was to perform meteorological modeling of the region around Fairbanks and North Pole, AK, as part of the State Implementation Plan for fine particulate matter (PM2.5) analysis of the region. The Fairbanks / North Star region was designated a non-attainment area for the daily National Ambient Air Quality Standard (NAAQS) for PM2.5 by the Environmental Protection Agency (EPA); high PM2.5 concentrations for the area predominantly occur within stable boundary layers during periods of extreme cold and weak winds during the winter season. The air quality modeling component of the SIP utilizes atmospheric analyses generated by a meteorological model; therefore it is important to select a meteorological model configuration that can properly represent the structure and evolution of the local stable boundary layer in these conditions.

The simulations were to be performed with the Weather Research and Forecasting (WRF), Advanced Research WRF (WRF-ARW) model, a globally used and freely-available meteorological model. Initial WRF-ARW simulations for a period in Jan. – Feb. 2008 were performed by Penn State under the Regional Applied Research Effort (RARE) project funded by the EPA. During the RARE project an optimal set of physics options, grid configuration, and data assimilation strategy was developed and tested. For physics sensitivity tests data assimilation was only performed on the coarser two domains (12-km and 4-km horizontal grid spacing), while the finest domain (1-km horizontal grid spacing) was used for assessing sensitivity. It was concluded, however, that a final meteorological analysis to be provided to EPA should also have data assimilation on the finest domain, to provide a better fit to the observations.

For the current contract, the model setup from the RARE project was to be applied to the production of a new meteorological analysis covering the period 2-17 Nov. 2008. As in the final meteorological analysis of the RARE project, data assimilation for the current project uses data assimilation on all three domains. However, a few modifications to the data assimilation procedure were implemented to take advantage of data and source code not used in the RARE project: 1) the effective vertical resolution of the observations as seen by the data assimilation modules was increased; 2) a more vertically-consistent objective analysis procedure was used; 3) additional surface observations from non-standard sources (i.e., stations not present in the standard METAR-format database typically used for hourly meteorological reporting) were used

both for verification and in the data assimilation, in order to supplement the METAR observations in this relatively data-sparse region.

A test period (5 – 9 Nov 2008) was used to perform some initial evaluations of possible modified procedures. In particular, during the RARE project the data assimilation on Grid 3 for the final meteorological analysis only used the temperatures from the METAR surface stations, and not the winds. For the RARE project it was thought that, since the surface winds during the coldest episode would be expected to be weak and poorly sampled, and since the surface winds in these conditions might be expected to be thermally-driven, the best chance of accurately reproducing existing flows would be to only use the temperature (and moisture) fields from surface observations in data assimilation, while relying on the model itself to generate the proper wind fields. This led to realistic low-level flow patterns and generally satisfactory wind error statistics at non-calm locations. There did tend to be a positive near-surface temperature bias during periods of extreme cold and weak winds, which could have been a result of overestimated vertical mixing due to the model's positive near-surface wind speed bias. The extended surface dataset used in the current study provided an opportunity to determine if improved statistics could result if 1-km grid data assimilation of near-surface winds was included. This was one of the initial sensitivity tests performed for the test period.

The major findings of the current project are as follows:

- The use of near-surface winds in data assimilation during the test period, when compared to a control simulation, led to about a 20 degree improvement in the mean absolute error (MAE) of wind direction. Temperature and wind speed statistics were also improved, but the improvements were modest. The modest size of these improvements was hypothesized to be due to either insufficient horizontal resolution of the model topography, or too large of a region of influence of particular observations in the data assimilation procedure.

- A new simulation was performed in which the radius of influence of observations on the 1-km grid was reduced from 75 km to 30 km, and the strength of the relaxation coefficient was doubled. These experiments produced slightly better temperature statistics on average, but slightly worse wind speed statistics. Wind direction errors, however, were further reduced by the new simulation procedure by a substantial amount (about 19 degrees in MAE). It was decided to make this model configuration (experiment TWIND2X30) the basis of a simulation of the entire 2-17 Nov. 2008 episode.

- Previous experiments did not make use of calm wind observations in the data assimilation procedure; the possible presence of missing data or high instrument response thresholds imply that it might be preferable to retain model-generated flows in weak-wind conditions rather than relax the flows towards a zero-magnitude wind vector by data assimilation. However, because it was desired to further reduce the model positive wind speed bias, an additional set of simulations over the 2-17 Nov. 2008 episode was performed, for which data assimilation did make use of calm wind reports (henceforth experiment TWIND2X30CALM). While the use of calm wind reports did reduce the positive near-surface wind bias of the model, the improvement was only on the order of 0.1 m s^{-1}. Meanwhile, TWIND2X30CALM had wind direction MAE scores that were about 14 degrees worse. Since wind direction by necessity can only be verified with non-calm wind observations, the implication was that the use of near-surface calm wind observations in data assimilation was degrading wind direction statistics at other observation locations without making a substantial improvement in wind speed statistics. Therefore, it was decided to deliver the results of TWIND2X30, rather than TWIND2X30CALM, to ADEC for use in subsequent air quality modeling.

- The Jan-Feb 2008 episode simulated during the RARE study was re-simulated using the TWIND2X30 procedure, and compared with corresponding statistics using the RARE configuration. Little statistical difference was found between the RARE and TWIND2X30 for variables other than wind direction, for which the TWIND2X30 configuration was about 12 degrees better in terms of MAE.

- Qualitatively, it was found that the meteorological analysis produced realistic topographical flows, and was capable of reproducing observed surface temperatures below -40 °C in locations such as Woodsmoke. However, the model did tend to have a positive near-surface temperature bias during the coldest episodes at valley locations that could not be well-resolved by the model (e.g., Goldstream Creek). This was counteracted by periods when the model had a negative temperature bias, such as during the initial precipitation event of the 2-17 Nov. 2008 episode, such that the overall model temperature bias was quite small (less than a degree Celsius) for both simulated episodes.