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A method for targeting air samplers for facility monitoring in an urban environment

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HIGHLIGHTS

- We demonstrate a method for comprehensive equipment siting for airborne emissions.
- Utilizes a longer climate record while retaining the frequency of occurrence.
- Urban atmospheric dispersion models are coupled with an interior dispersion model.
- Uses predicted downwind concentrations/dosages for each meteorological pattern.
- Frequency of occurrence and dosage is used to generate PoE spatial maps.

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ABSTRACT

There are a variety of applications that require the use of comprehensive specification of the weather conditions combined with an analysis that uses detailed modeling and simulation. The combination of these two elements can make it difficult to achieve the desired level of fidelity in a logistically feasible way. An example of this type of application is the deployment of surface-based sensors/samplers, which is a common practice for emission, and air quality monitoring purposes where the proper selection of sites for the measurement equipment is critical to an accurate characterization of the emissions. This is particularly true in urban environments where the limited availability of suitable sites and the non-intuitive dispersion patterns associated with the wind flow around the buildings and through the urban canyons make site selection difficult. This article demonstrates an improved methodology for optimally locating for air quality monitoring equipment within this complex and challenging environment. The methodology involves a) the utilization of a longer climatological record of meteorological observations or gridded reanalysis products to better represent the full range of representative meteorological conditions; b) reduction of the full climatological record into a subset of characteristic meteorological patterns and associated frequencies of occurrence, utilizing a multi-dimensional feature extraction and classification technique known as a Self Organizing Map (SOM); c) downscaling and diagnosis of the urban area building-aware wind flow fields for each characteristic meteorological pattern; d) atmospheric transport and dispersion (AT&D) simulations for each downscaled meteorological pattern, utilizing a building aware Lagrangian particle dispersion model; and finally e) the combination of predicted downwind concentrations/dosages for each meteorological pattern with their associated frequency of occurrence are used to generate Probability of Detection/Exceedence spatial maps for prescribed concentration thresholds or standards. The method is flexible and can be tuned to allow the detailed characterization of Probability of Detection (POD) for a given sampler detection threshold and sampling period (e.g. sampling duration, season, time of day). An example of this methodology is illustrated for a single facility in an urban location surrounded by numerous multi-story buildings.

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1. Introduction

Airborne contaminants are a common by-product of modern industrial societies and numerous government and non-government organizations are tasked with monitoring these emissions to assess their impact on the environment. For example, within the United States (U.S.), the deployment and operation of air monitoring equipment remains a critical component of the U.S. Environmental Protection Agency (EPA) overarching air quality program, as required by the 1970 Clean Air Act (CAA). In addition to requiring states to establish regional scale air monitoring networks (e.g. the State and Local Air Monitoring Stations (SLAMS) network) to monitor compliance with the National Ambient Air Quality Standards (NAAQS), the CAA also requires the establishment of source-oriented monitoring sites near specific pollutant (namely lead) generating sources, which emit a certain quantity of pollutant per year or more (>0.5 tons per year for lead) (EPA, 2010). Optimal air quality monitoring is also critical to U.S. law enforcement, homeland security, and national defense organizations which are tasked with detecting and identifying the intentional release of chemical and biological (CB) agents into the atmosphere and warning and/or mitigating the effects on the public and/or military forces. The common challenge amongst all these organizations is the optimal placement of air monitoring equipment to maximize probability of accurately measuring or detecting the emitted airborne material. This is particularly challenging in urban environments where the limited availability of suitable sites to deploy instrumentation and the non-intuitive dispersion patterns associated with the wind flow around the buildings and through the urban canyons make site selection difficult.

A common approach for conducting air quality emissions studies and for assessing where to deploy monitoring instrumentation involves running a series of dispersion simulations across a representative set of meteorological conditions that influence the Atmospheric Transport and Dispersion (AT&D) for a given area. The representativeness of the meteorological data is influenced by a number of factors: complexity of the site under consideration, proximity of the weather data collection to the area of interest, and the period over which meteorological data are available. These factors vary seasonally and by location, and of critical importance is that the meteorological data cover the full range of likely conditions, including outliers that can produce a T&D event of significance (EPA, 2005). Landsberg and Jacobs (1951) examined distributions of atmospheric conditions over different time periods and found that periods in excess of ten years may be required to obtain stability of frequency distributions in weather observations. Burton et al. (1983) also examined the issue of observation record stability through a study of frequency distributions in observational records and their impact on atmospheric dispersion simulations. In this study the authors compared the concentration results from dispersion simulations that used observations of various lengths of time relative to simulation results based on a 17-year record. The goal of their study was to characterize the minimum length of observational meteorological data required to approximate the results produced from a 17-year observational record. The results of this study indicate that for a single location the variability in the dispersion model results were sufficiently reduced if a meteorological record of 5 years or greater were used. Based on the results of Burton et al. (1983), the United States Environmental Protection Agency (EPA) suggest using at least one year of meteorological data in air quality analyses that utilize dispersion simulations and strongly recommend using five years of data (EPA, 2005). With the increasing availability of faster, low cost computing, it is now possible to complete a 5-year assessment of material concentrations in a reasonable amount of time with many of the commonly used dispersion models.

However, if the assessment requires multiple coupled models or higher fidelity simulations, it is still prohibitively expensive to complete such an analysis with the recommended meteorological data sets. Kolczynski et al. (2009) provides an example of how to address this challenge by determining the uncertainty and variation in the weather for a location directly from the climatological record and then using these results in an ATD model capable of directly utilizing this information. While this approach provides an alternative solution that allows the incorporation of information from a longer climatological record, the ATD model used in this study is not capable of using this type of information. Furthermore, because the Kolczynski et al. (2009) method drives the ATD model with information derived from the ensemble statistics of the climatology, it differs significantly from the method presented here which identifies a series of specific date and time combinations that represent this same variance in the weather. The advantage of the method presented here is that it drives the ATD model with physically consistent weather from an actual event in contrast to climate statistics which may not may not be a physically scenario for driving the ATD model.

The approach described in this paper was designed to make it logistically feasible to conduct a complex dispersion modeling

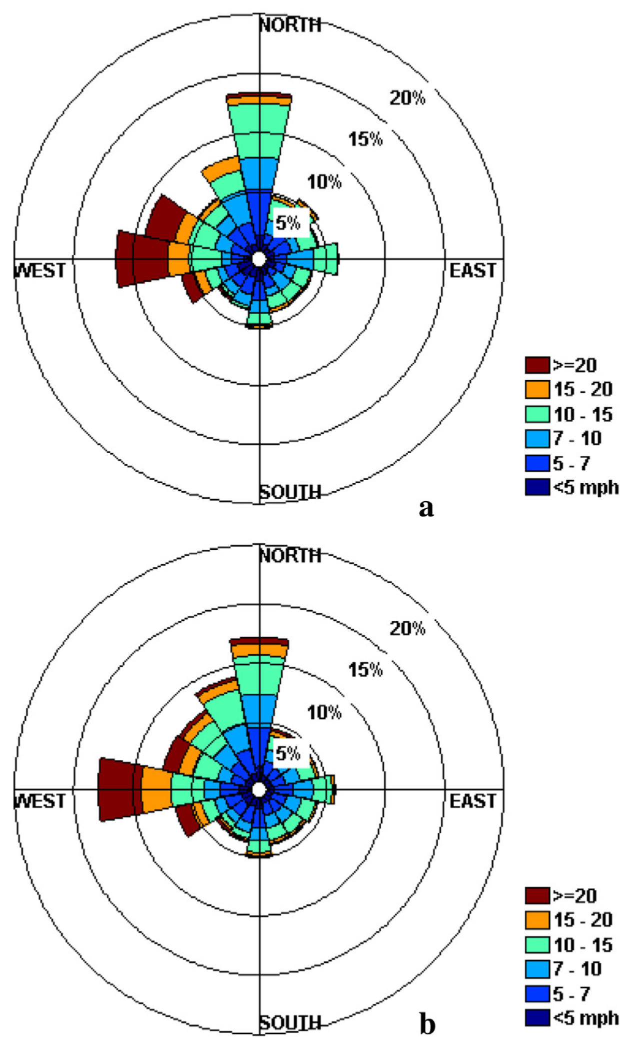

Fig. 1. A wind rose depicting the wind speed and direction observations from the Rocky Mountain Metropolitan Airport (a), and a wind rose derived from the SOM technique (b). The wind rose shown in a is made up of 181421 individual records while the wind rose shown in b is made up of 1420 individual records.